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WAR DEPARTMENT

TECHNICAL MANUAL

NOTES ON EYE, EAR, NOSE, AND THROAT IN AVIATION MEDICINE

TECHNICAL MANUAL No. 8-300

WAR DEPARTMENT,
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NOTES ON EYE, EAR, NOSE, AND THROAT IN AVIATION MEDICINE

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SECTION I

GENERAL

1. **Mouth.**—*a. General.*—This organ has four main functions: It is the entrance of the alimentary canal; it aids in the mastication of food; it has an important role in speech; and it is an auxiliary entrance and exit for the respiratory system.

Practically all defects which would be disqualifying are easily seen or are distinguished while watching and listening to the individual talk. Applicants with gross defects of the mouth will rarely present themselves for examination, and for this reason the inspection of the mouth may frequently be neglected.

b. Disqualifying defects.—(1) *Harelip.*—This developmental defect occurs in a variety of forms varying from a simple defect of the lip to a bilateral defect involving the lip, the alveolar ridge of the maxilla, and the hard and soft palates. Any extensive defect is usually accompanied by some defect in speech even when corrected. Obviously, applicants with marked defects of this nature will seldom present themselves for examination. Certain minor cases which have had only the lip involved, and which have been satisfactorily corrected so that the resulting scar is not ugly, the function is not interfered with, and the speech is normal are acceptable for training.

(2) *Loss of whole or large part of either lip or unsightly mutilations of lips from wounds, burns, or disease.*—Such defects require little comment. They are so obvious that they will probably never be missed, but occasionally an applicant will appear who has a rather severe, unsightly scar or deformity of the upper lip camouflaged beneath a mustache; so particular attention should be paid to the mouths of applicants who have such ornaments.

(3) *Tumors of lip.*—Hemangioma are frequently located in the lower lip. If small and nonprogressive, they may be disregarded. The larger ones are disqualifying, both from a cosmetic standpoint and because of the possibility of severe hemorrhage following trauma.

It is to be remembered that the lower lip is a very frequent site for the appearance of epitheliomas, especially in males above the fourth decade of life.

The exact cause for this is not known, but overexposure to sunlight and chronic irritations are predisposing causes. Aviators, especially in this part of the country, have had extreme exposure of the lips to the sun, and they are subjected to special trauma in the use of oxygen nipples. Particular attention should be paid to the inspection of the lips in the semiannual examination as these cancers can be cured in a large percentage of cases if recognized early.

2. Face.—*a. General.*—Inspection of the face is done automatically during the examination of the eyes, nose, mouth, and ears.

b. Disqualifying factors.—(1) Extreme ugliness.

(2) *Deformities.*

(*a*) Large birthmarks.

(*b*) Large hairy moles.

(*c*) Extensive scars.

(*d*) Mutilations due to injuries or operations.

(*e*) Tumors.

(*f*) Ulcerations.

(*g*) Fistulae.

1. Parotid.

2. Bronchial.

3. Dacryocystitis.

4. Osteomyelitic.

(*h*) Atrophy of part of face, if extensive.

(*i*) Lack of symmetrical development. Practically no individual has a pure symmetry of the two sides of the face and asymmetry occurs in many degrees. Only those which are conspicuous enough to be readily noticed, or in which the condition interferes with function are disqualifying. Like ugliness, this is entirely a matter of opinion of the examiner.

(3) *Persistent neuralgia, tic doloreaux.*—The diagnosis of these conditions is obtained from the statements of the patient and they will seldom be found. Any paralysis of the muscle of the face manifested by a ptosis of the lids, a sagging of the mouth, inability to control the muscles of expression, or a masking of facial expression are disqualifying.

(4) Ununited fractures of the maxillary bones or deformities of these bones interfering with mastication or speech or any disease of these bones such as extensive exostosis, caries, necrosis, osteomyelitis, or cysts are disqualifying.

(5) The temporomandibular joint must be free from arthritis and have normal function. The conditions affecting the bones of the face are usually diagnosed during the dental examination. Occasionally an exostosis of the hard palate is seen at the site of fusion. Unless these are large and interfere with speech or the surface is ulcerated, they may be ignored. Applicants who have large tumors of this nature should be temporarily disqualified until the tumor has been removed.

3. Teeth.—*a. General.*—As a rule, the examination of the teeth is made by the dental officer, but there will be times when a dentist is not available and in such cases the examiner should know what the dental causes of disqualification are.

The requirements for applicants for flying training are the same as for West Point candidates and are covered in AR 40–100.

b. Disqualifying factors.—(1) *Insufficient number of masticating teeth.*—The regulations require a minimum of six vital masticating teeth above, and six below, serviceably opposing. The principal points to look for may be teeth which do not occlude and nonvital teeth. Doubtful teeth should be X-rayed. In regard to the number of masticating teeth, if a case has an insufficient number of teeth, the unerupted third molar may be counted. If a normal third molar, properly positioned and developed is shown, it may be assumed that it will have a normal eruption and the candidate may be credited with possession of this tooth. In such case the report of physical examination will carry an appropriate remark such as "X-ray shows normally developed and erupting (specify tooth or teeth)." In doubtful cases a duplicate of the X-ray films will be forwarded with the physical examination form. This authorization is important because a large majority of our applicants are of the age group in which a large number of third molars are still unerupted.

(2) *Insufficient number of anterior teeth.*—The regulations require a minimum of four natural, vital anterior teeth (incisors and cuspids). Again attention is called to the word vital.

(3) *Absence of three adjoining masticating teeth in either side of upper or lower jaw.*—For example, the absence of the first and second bicuspids and the first molar, or the second bicuspid and the first and second molars, or the first, second, and third molars in either side of upper or lower jaw would mean disqualification.

(4) *Disfiguring spaces between anterior teeth.*—This is a matter of judgment of the examining officer and, if questionable, casts would have to be made and forwarded to The Surgeon General's Office for decision.

(5) *Marked irregularity of the teeth.*—This also depends on the judgment of the examining officer and, if doubt exists, casts would have to be forwarded.

(6) *Marked malocclusion.*—This again is a matter of judgment. The applicant is instructed to close his mouth normally and the relationship of the opposing teeth is noted. If there is any marked lack of uniformity, the applicant should be sent to a dental officer to have casts made for forwarding to the office of The Surgeon General. Marked malocclusion has been one of the chief causes of rejection of applicants who report to the training center for duty. Also a great many cadets reporting have defects which place them in class I or II. In case minor defects such as caries, gingivitis, heavy deposits of calculus, teeth to be extracted, or other conditions which need correction are found, the candidate's papers should be held pending the receipt of a certificate from his dentist to the effect that the defects have been corrected. An applicant should be an actual class IV case and need but little dental work during the flying training course.

In the semiannual examination of pilots a rigid inspection of the teeth is essential. Rapid changes in temperature and the use of oxygen nipples are deleterious to fillings and inlays. Frequently the first sign of nervousness is detected in the unconscious habits of movements of the mouth and tongue and these mannerisms are very often centered upon a maloccluded or a roughened tooth. Such a case requires not only correction of the dental defect, but mental training as well.

4. Tongue.—The tongue is an important organ in assisting in mastication, speech, and swallowing. It is the site of many abnormalities of development and these must be judged as to how they affect the function. Partial loss, hypertrophy or atrophy, split or rigid tongue, adhesions of the tongue to the side of the mouth, or shortening of the frenum of the tongue (tongue-tied) are all disqualifying if they interfere with function. The tongue is frequently the site of relatively benign tumors of the hemangioma or lymphangioma type. If these are extensive, they are disqualifying. The presence of glossitis is usually indicative of some other disease, and such a condition should suggest the possibility of pellagra, sprue, pernicious anemia, syphilis, tuberculosis, diabetes, nephritis, or poisoning with the heavy metals.

In the semiannual examination care should be taken to notice the first signs of leukoplakia. This condition, which begins first as a thin whitish plaque and as it progresses becomes a thickened grayish fissured mass, is usually considered as being the result of a chronic irritation, such as jagged teeth or improperly fitted dentures or smoking, particularly pipe smoking where the hot draft of smoke is drawn against one spot. There is apparently some relationship to syphilis

also, as quite a large percentage of people with leukoplakia have a positive Wassermann. These patches may appear on the tongue, on either side of the gums, or on the lips. The condition is of extreme importance because of the relationship between these plaques and carcinoma. Even in the early states the condition is very resistant to treatment.

5. Ranula.—Ranula is a term which has been applied to all cystic swellings of the floor of the mouth, whatever their form or origin. The origin of the word is uncertain and the term may have arisen from the resemblance of the smooth tumor to the belly of a frog or because people with large ranulae have a croaking voice.

The tumors may be cystic swellings of the mucous and sublingual glands, cysts of Blandin's gland, congenital ranulae, acute ranulae, traumatic ranulae, or large burrowing multilocular ranulae. They probably all arise in the floor of the mouth and from there spread or burrow through the muscles of the neck. Many are in connection with the submaxillary gland and are due to calculi. Whatever their origin or type, the treatment is excision and this is frequently a very tedious and complicated procedure. The condition must be corrected before the applicant is accepted.

6. Tonsils.—In the past few years more and more applicants have their tonsils present. This is due to the fact that the indiscriminate removal of tonsils which prevailed years ago has ceased and now the tonsils are removed for a definite reason.

The following are generally accepted as being indications for tonsillectomy:

a. Recurring attacks of tonsillitis or peritonsillitis.

b. Interference with respiration or glutition.

c. Chronic infected tonsils which are considered as the focus of infection in certain systemic conditions.

d. Recurring joint symptoms following attacks of acute or subacute tonsillitis.

e. Proof that the tonsils are carriers of diphtheria.

f. Chronic enlargement of the cervical glands, especially those situated near the angles of the jaw.

g. Recurring attacks of otitis media. (In children under 3 years adenoidectomy only is usually done.)

In all cases in which applicants have tonsils or adenoids the examiner will decide whether they should be removed prior to his acceptance, bearing in mind the intense nature of the flying training course. No applicant should be accepted who will possibly be hospitalized for some condition which can just as well be corrected be-

fore he arrives here. Cases with tonsils that the examiner believes should be enucleated and in which no other defects are found may be temporarily disqualified and upon completion of the treatment or operation a certificate may be forwarded by the applicant showing that the temporary disqualification has been corrected.

7. **Pharynx.**—Under this heading is included the postnasal adenoids. If these are hypertrophied sufficiently or if there is a history of otitis media they are a cause of rejection. The hypertrophy of the adenoids has a greater significance as regards flying personnel because of the location of the nasal end of the eustachian tube in their vicinity. Moderate inflammation of hypertrophic adenoid tissue may be sufficient to interfere with the normal function of this tube with a resulting severe involvement of the middle ear. Occasionally in the process of development of the nasopharynx there is an incomplete formation of the postnasal space or an atresia, either total or partial. This condition, while hardly to be expected in applicants for flying training, is of some differential importance in children. Probably many children are subjected to adenoidectomy for the correction of mouth breathing when the condition is the result of nondevelopment of the postnasal space, which in most cases corrects itself with the growth of the skull. If they are operated upon the resulting scar tissue makes the stenosis worse rather than better.

Any perforation, loss of substance, or ulceration of the hard or soft palate, or extensive adhesions of the soft palate to the pharynx are cause for disqualification.

The loss of the uvula which occurs rather frequently as a result of excision at the time of tonsillectomy is not to be considered disqualifying unless it is so extensive as to interfere with speech or swallowing. A paralysis of the soft palate, which occurs as a result of postdiphtheritic neuritis or in association with central nervous system lesions, apoplexy, embolism, or tumors pressing on the bulb or from any other cause is disqualifying. This condition can usually be rather easily recognized as the patient has a tendency for fluid to regurgitate into the nose and has vocalization difficulties and cannot pronounce the word "wrong." A "b" becomes an "m" and the "d" an "n." In saying "egg" he says "eng."

8. **Larynx.**—The larynx is not routinely inspected, but the presence of speech defects, husky voice, hoarseness, a persistent desire to clear the throat, dysphonia, or scars on the neck in the region of the larynx call for such an examination. The most satisfactory examination can be made by the direct method. However, with a little practice a good view of the larynx may be had by the laryngoscopic mirror.

Chronic laryngitis, paralysis, partial or total, of the vocal cords, tumors, either benign or malignant, of the larynx or adjacent structures are disqualifying.

SECTION II
NOSE

9. General.—This prominent organ is of extreme importance to the flyer. Adequate nasal respiration is essential because of rapid changes in altitude and prolonged flight at high altitudes. The sense of smell is of secondary importance, but an anosmia is a disqualifying factor. Furthermore, it is of prime importance that the structure of the nose permits adequate ventilation and drainage of the accessory sinuses, the nasal lacrimal ducts and the eustachian tubes.

10. External nose.—The loss of the nose, or any deformity of the nose which produces an ugly appearance, or ulceration of the external nose are causes for rejection. While it would be ideal if all Air Corps officers had a classic type of nose with a rectilinear dorsum and a horizontal inclination of the base that corresponded to the individual's type of face formation, such a Utopian condition is not possible. The main concern in this examination is to select normally functioning noses. The shape and form of the external nose does have an important clinical aspect, however, as this prominent organ is frequently grossly mutilated in airplane and auto crashes. In these cases the immediate attempt at restoration of the normal contour is essential. This will be discussed later.

The external nose is a constant source of irritation to most flying trainees during the early period of training. There is a considerable blast of air on the face due to the structure of the primary training airplane and this, associated with the unaccustomed use of goggles which press rather firmly over the infratrochlear, the supratrochlear and nasociliary nerves, produces a very annoying itching sensation. The prominent position of the nose and the entire lack of protection from the sun that the present helmet gives, results in many cases of severe sunburn. This especially is true in personnel flying long missions in the tropics. A good prophylaxis against this condition is to paint the nose prior to take-off with a 40 percent solution of compound tincture of benzoin in alcohol.

11. Cavity.—*a. Description.*—The nasal cavity is a fairly simple inlet and exit for the respiratory system. It consists of a passageway separated normally into two equal halves by the nasal septum. In the anterior portion, just inside the vestibule, we have a filter for the removal of gross dust and the prevention of entry of foreign objects such as insects. This filter is formed by the cilia of the internal epithelial-lined vestibule. Further protection is afforded by a backfiring mechanism, a fairly simple reflex nervous action, in which foreign particles or irritants excite the act of sneezing. Within the nose on the lateral wall of each half we have three baffle plates with automatic thermostatic and hygroscopic control, the turbinate bodies. They are named from above downward: the superior (very small, not visible); the middle (somewhat larger and visible); and the inferior (the largest and plainly visible on examination). These turbinate bodies are composed of a bony base, the upper two outgrowths from the ethmoid bone, while the lower one is an independent osseous unit. They are covered with a mucoperiosteum and contain erectile tissue. The space below each turbinate is called a meatus and designated from above downward as superior, middle, and inferior. The superior meatus has the openings of most of the posterior ethmoid cells. The middle meatus on its lateral wall has the opening of the maxillary sinus, while in the suprabulla fossa the middle ethmoid cells have their ostia. In the frontal recess the frontal sinuses and the anterior ethmoid cells have their exits. In the inferior meatus about 30 to 40 millimeters from the nares is located the ostium of the nasolacrimal duct. Posteriorly the nasal passages communicate with the nasopharynx.

b. Functions.—(1) It is the air passageway for the respiratory system with the important subsidiary function of warming and moistening the inspired air.

(2) It is the organ of smell, the direction of the inspired air bringing a fairly large quantity over the end organs of the olfactory nerve.

(3) It is the drainage area of the nasolacrimal duct and the nasal accessory sinuses. These sinuses are integral parts of the nose and aid in conditioning the inspired air.

12. Obstruction.—Clinically the two most common symptoms of nasal disorder are—

a. Nasal obstruction and an undue amount of discharge from the nose.

b. Discharge of pus or other symptoms of empyema of the sinuses.

The general conditions which cause nasal obstruction are frequently overlooked. Often it is the result of venous stasis with a

resulting congestion and hypertrophy of the mucous membranes and turbinates. Common causes are overeating, overdrinking, lack of exercise, fear of cold, and the use of too heavy clothing.

13. Septum.—The septum consists of a partition composed of cartilage and bone covered with mucous membrane, which separates the two nasal passages. Deformities of the septum result in the most frequent cause of rejection of applicants in the nose and throat examination.

The location of the nose makes it particularly liable to trauma and these repeated blows from childhood onward result in a variety of derangements of the constituent parts of the septum. Naturally deviations occur more frequently in males than in females and are more common in adult life. However, children do fall on their noses, and so it is not surprising to find that over 30 percent of children at the age of seven have some deviation. The finding of a perfectly normal septum in our examination is somewhat of a rarity, and the question of how severe the deformity must be to cause rejection must be considered from the angle of impairment of function.

a. Available air space.—To say that the applicant should have four-fifths of his natural air space would be a good conservative basis. It is to be remembered that what appears to be an adequate space under normal conditions will, under the influence of congestion, be practically closed, compensatory hypertrophy of the turbinate on the concave side of the depression being of very common occurrence.

b. Location of deviation.—Deviations which occur in the region of the drainage areas of the sinuses should be corrected. These occur principally high and posterior where they are not so readily seen.

c. Deviations which impinge on adjacent structures.—The most common is a spur formation impinging on the inferior turbinate. Frequently these result in chronic ulceration of the turbinate, with crust formation. A common type of deviation is that in which the anterior cartilage and vomer are dislocated from the sulcus of the nasal crest, resulting in a long overhanging shelf on one side. In repairing this condition it is well to remember that you will have four layers of mucous membrane due to its folding.

d. Deviations which cause ulceration or potential hemorrhage.—Very sharp angular deviations, sharp spurs, large spurs, and deviations of such an extent that the mucosa is stretched and becomes atrophic are frequently the sources of ulcerations and hemorrhages. These must be corrected.

The operations for the correction of these conditions of the septum are well known and they do not present a major risk. All defects of

this nature to be corrected prior to acceptance and, as in the cases who require tonsillectomy, they are disqualified until the correction is made. In these cases it is a good idea to make enough of the total examination to be fairly certain that the applicant is otherwise qualified, as it is very embarrassing to send an applicant to have his nose operated and when he returns with a very fine looking nose to find he has a vision of, say, 20/50.

14. Polyps.—Polyps are usually seen in the region of the middle turbinate and consist of polypoid degenerations of the turbinate body, the result of prolonged irritation by discharges, or as protrusions of polypoid membranes from the ethmoid or maxillary sinuses. Most polyps are complications of chronic sinus disease, and unless it can be proved to be a benign simple polyp and that the sinuses are entirely free from infection, the case is disqualified.

15. Accessory sinuses.—The nasal sinuses should be considered as integral parts of the respiratory system. They are outpouchings of the nose, the lining mucous membrane of which is continuous with that of the sinuses. In this short outline we cannot attempt a discussion of sinus disease and its treatment, but all examiners should be familiar with the objective signs of chronic sinus disease, as acute or chronic infections of the sinuses are disqualifying.

Precautions are necessary in considering a positive history of sinus disease as many patients have been told that they have sinusitis when they have only the normal inflammation of the sinuses that accompanies practically all cases of acute rhinitis. For some reason, many individuals consider it rather an honor to have a history of sinusitis and recall these diagnoses with pride.

a. Objective signs of chronic maxillary sinusitis.—(1) A discharge of pus from the nose which may be foul.

(2) Pus beneath the midturbinate which reappears after removal.

(3) Boggy appearance of the turbinates with a possible polypoid degeneration of the midturbinate or even a blocking of the nose with definite polypi.

(4) Darkness on transillumination.

b. Objective signs of frontal and ethmoid sinusitis.—Ethmoiditis may occur without frontal sinus involvement but frontal sinus involvement without ethmoiditis is quite rare.

(1) Discharge of pus from the nose and collections of pus beneath the midturbinate. In a typical case the discharge is more apt to be constant than in the case of maxillary disease.

(2) Polypoid degeneration and polyp formation.

(3) Tenderness over the sinuses.

(4) Oedema of the lids.

The presence of these symptoms calls for further study such as X-ray of the sinuses or a diagnostic puncture. All cases which show a polypoid degeneration of the mucous membrane about the middle turbinate or the presence of polyps should be considered as probable sinus cases unless it can be shown that the sinuses are negative and the case is one of a simple benign polyp.

Section III

MAXILLO FACIAL INJURIES

16. General.—The repair of injuries about the face is closely associated with ophthalmic and otorhinological surgery. The proper understanding of the fundamental therapy in these cases is essential to the flight surgeon.

In airplane crashes, as in auto crashes, injuries to the face and head occur in a large percentage of cases. If the trauma is not fatal, it is the duty of the flight surgeon to immediately start the repair of these defects. It has been stated that "except trauma of vital organs and their essential coverings, the final outcome of no injury is so directly dependent upon early proper care as injury of the face."

The commonest injuries following crashes are—

a. Lacerations of skin of face varying from small abrasions to extensive loss of tissue.

b. Injuries to the nose.

c. Fractures of mandible, maxilla, and malar bones.

d. Injuries to orbit and its contents.

17. Lacerations.—Immediate suture after debridement naturally offers the best chance of a good scar, and extensive lacerations should be treated as emergencies. It is of utmost importance in the repair of face injuries to preserve all possible tissue and in placing sutures those for tension should be placed in the deep structures. The underlying structures must be repaired and returned as near as possible to their original position before suturing the overlying skin.

Lacerations of a scooped nature with beveled edges require immediate suture. Other types of lacerations which require immediate suture are those involving all narrow double-surfaced flaps, such as the border of the lips and the ear or eyelids, these to be sutured on

both sides if possible. Any laceration into or through substance of the ear, especially if there is a large flap attached by a narrow pedicle, all cuts or tears of the nasal skin and cartilages including the septum.

18. Injuries to nose.—Injuries to the nose are to be treated as emergencies, with replacement and mobilization as soon as possible. Neglect of these injuries results in deformities, obstruction to breathing, and possible involvement of the sinuses.

Depressed fractures of the nose are usually rather easily replaced by pressure from within. Care should be taken to examine the septum for evidence of dislocation from the maxillary groove. In replacing and remodeling these nasal fractures some form of anesthesia is necessary. Local intranasal cocain packs with novocain injection of the nasal labial angles and the infraorbital nerves are very satisfactory. Short inhalation anesthesia is sometimes sufficient. Also, if the patient is in good condition, the use of intravenous anesthesias gives excellent results.

Many of these nasal repairs retain their position without support. In other cases some form of splinting is advisable. The appliance of Straith for the maintenance and correction of severe nasal and labial deformities is one of the best.

In regard to early treatment of nasal injuries, a case of complete amputation of the nose by a butcher knife has been reported in which the amputated part was resutured and the nose saved.

19. Fractures of facial bones.—Fractures of the mandible when teeth are present are best treated by interdental wiring. This is also the method of choice of the neck, the condyles, and the intermuscular part of the ramus. In maxillary fractures which involve the alveolar bone the displaced fragments with attached teeth should be replaced and held by means of wires or other appliances. A common type of maxillary fracture seen after airplane crashes consists of a mashed posterior displacement with comminution and compression. These are best replaced by prolonged elastic traction between an extension bar on a head cap and some form of dental appliance attached to the teeth of the maxilla. Malar bone fractures are rather common and frequently overlooked. They usually take the form of a fracture dislocation of the malar from the maxilla, the frontal, and the zygomatic arch. The X-ray picture may be frequently misinterpreted. Palpation of the orbital margin will reveal a depressed defect of the margin. These fractures require early reduction for defects here result in a change in the position of the eyeball which is most disfiguring and in which binocular vision is usually impossible. Several methods for the reduction of this type of fracture

are used, namely, the intraoral method, the intramaxillary sinus method, the hook method, and the Gillies method. Gillies is usually the most satisfactory. A long slender bone elevator is introduced through a temporal skin incision and carried downward over the temporal muscle and beneath the zygonatic arch and then, by prying, the bone is raised into position. Usually no support is necessary to maintain position.

20. Injuries to orbit.—Injuries about the eyes are frequent following crashes, the most typical being a circular or partial circular tearing laceration resulting from the driving inward of the rim of the goggle. Particular attention should be paid to the possibility of laceration of the levator palpebral and to laceration involving both surfaces of the lids. Early suture will prevent the development of ptosis, entropion, or ectropion. Injuries involving the eyeball will not be discussed in this outline.

SECTION IV

EXTERNAL AND MIDDLE EAR

21. General.—The total loss of an external ear, marked hypertrophy or atrophy, or disfiguring deformity of either ear such as results from lacerations, burns, or tumors are disqualifying. Atresia of the external auditory canal or tumors involving this canal are disqualifying. Otitis media, acute, chronic, suppurative, or catarrhal is disqualifying. In respect to acute otitis media at least 6 months must have elapsed without remission or sequelae in order to qualify an original applicant.

A mastoidectomy is disqualifying. In this disease it would seem logical to differentiate between a simple posterior drainage of the antrum of the mastoid and an extensive destructive cure of an osteomyelitis of the mastoid process. At the present time it is the policy to grant waivers in cases of simple mastoidectomies which have normal hearing, normal vestibular responses, and in which the scar is not disfiguring.

22. Tympanic membrane.—The appearance of the tympanic membrane and the acuity of hearing give the examiner the only objective signs of past or present disease of the middle ear. The membrane in a large majority of cases is readily seen if the cerumen and

debris is cleared from the external auditory canal. Pathology is usually very clearly seen, especially with the newer magnifying self-illuminated otoscopes.

In examining the tympanic membrane, the following conditions are noted:

Luster or color.
Transparency.
The cone of light.
Edema.
Bulging.
Retraction.
Thickening.
Tension.
Perforations.
Scars, extent.
Adhesions.
Calcium deposits.
Appearance of the malleus.
Appearance of Shrapnell's membrane.
Movability of the drum.

Occasionally a cadet appointee has a chronic otitis media with a perforation of the drum. The failure of the examiner to see this is possibly due to failure to clean properly the canal of the discharge and debris so that a clear view may be had, and the fact that the condition may be quiescent and the perforation not recognized. At times in very large perforations, when the ear is quiet, the posterior wall of the middle ear will give the appearance of a drum membrane if examined casually.

Retractions of the membrane are significant in that they may represent the sequelae of old otitis media or the lack of patency of the eustachian tube. Cases showing a retraction must have the eustachian tube catheterized to demonstrate the patency. Obstruction to the eustachian tube is a disqualifying defect.

Scars, thickening, loss of luster, adhesions, and deposits of calcium are all indicative of past inflammation. If extensive, they are disqualifying. Careful examination will usually show hearing defects in these cases.

23. Hearing tests.—Regulations state that the hearing in applicants must be 20/20 in each ear. That is, they must hear at 20 feet the whispered voice, this whisper to be made with the residual air, and among other symbols the numbers 66, 18, and 23 will be used. This is to determine roughly the auditory acuity in different pitches. In

those already qualified the hearing must be at 8/20 in each ear or 15/20 in one ear and 5/20 in the other. The regulations further state that when an audiometer is available it will be used, and for Class I the average hearing loss must not be more than 15 percent.

The usual examination for hearing is rather crude and nonstandardized. No two people use the residual air to make whispered tones in the same pitch or the same intensity. Proper attention to the use of a quiet room is seldom observed, and on the whole hearing tests as such give only a rough idea of the auditory sense.

The hearing sense is actually very discriminative and responds through a vast range of pitch and intensity. These two factors are the main components in sound, and while actually we seldom experience a sound of one pitch it does give a definite point for the recording and observation of hearing changes.

24. Pitch.—By pitch we mean the number of double vibrations per second making up the sound. This component is fairly easy of measurement. In the human ear the range runs from 20 as the lower limit to about 20,000 as the upper limit. Under average conditions, except for music, we have very little use for any hearing above 18,000. Even 18,000 is seldom heard by people who have reached middle age and by the age of 40 the upper limit has dropped to about 15,000; between 55 and 65 the upper limit has dropped to approximately 10,000 to 12,000, and at 75 the upper limit is seldom above 8,000.

The human ear hears best in the range between 500 and 5,000 vibrations, and this is also the most important range of the human voice. Specifically, for aviation, the tones around 1,024 are important as this closely corresponds to the radio beam signal.

25. Intensity.—*a. General.*—Unlike pitch, intensity of sound is difficult to measure. In all English-speaking countries the decibel is the standard unit for the measuring of sound intensities. A decibel is a unit which represents a definite pressure upon a definite area of drum membrane. The unit is logarithmic. There is a marked variation in the amplitude of vibration between sounds which are just barely audible and the upper threshold where sound becomes painful. Knudsen and Jones state that for sounds which are just barely audible in the range of 1,000 to 4,000 vibrations per second the pulsations of the sound waves within the external canal are so small that the amplitude of vibration of the drum membrane is only about one-billionth of an inch. In response to ordinary conversation the amplitude of vibration of the drum membrane is about one-millionth of an inch, or about 1,000 times greater than that of barely audible sound. In response to painfully loud sounds the drum membrane has an amplitude of vibra-

tion of about one-thousandth of an inch. That is about 1,000,000 times the amplitude of a barely audible sound. From the barely audible sound to the painfully loud sound, therefore, the amplitude of vibration of the drum membrane increases about one millionfold. Since the energy of vibration is proportional to the square of the amplitude, the intensity of a painfully loud sound is a million times the intensity of a barely audible sound.

b. Hearing tests.—At the present time the audiometer represents the most satisfactory method for the testing of hearing. However, it is essential that the hearing tests be done in as nearly a soundproof room as possible. If an applicant is tested in a noisy room it is not the testing of his hearing ability, but the testing of the threshold of hearing above the threshold of noise in the room. The findings are of little value to the examiner and if disqualifying are unfair to the examinee.

In experienced pilots a practical test of hearing ability is indicated. No such test is in use at the present time. Primarily it must be determined whether a pilot is able to hear and understand radio messages and signals. Experience and practice are important factors in the distinguishing of radio messages and many individuals who have very definite loss of hearing for ordinary conversation are still very efficient in using radio. Also the volume of the radio may be easily increased. Some form of a radio test, using a simulated broadcast under adverse weather conditions, would satisfactorily solve the problem of the hard-of-hearing pilot.

c. Range of sound.—The following table shows samples of the range of noise expressed in decibels:

Energy units	Decibels	Examples
10, 000, 000, 000, 000	130	Threshold of painful sound.
1, 000, 000, 000, 000	120	Artillery gunfire.
100, 000, 000, 000	110	Airplane cabin (not soundproofed).
10, 000, 000, 000	100	Subway car.
1, 000, 000, 000	90	Auto horn.
100, 000, 000	80	Tabulating machine room.
10, 000, 000	70	Stenographic room.
1, 000, 000	60	Average general office.
100, 000	50	Average quiet office.
10, 000	40	Average residence.
1, 000	30	Quiet farmhouse.
100	20	Underground vault.
10	10	One's own heart beat.
1	0	Absolute stillness.

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Section V

EFFECT OF FLIGHT ON MIDDLE EAR

26. General.—Those familiar with aviation medicine are well aware that airplane pilots suffer more frequently from disturbances of the middle ear than from all other occupational diseases combined.

The phenomenal growth of commercial air transport, which carried approximately one million passengers in 1936, makes this problem of interest and importance to the general medical profession, for airplane passengers are exposed to the same influences as the pilots during flight and in most instances are much more adversely affected.

Since the deleterious effects of flight on the middle ear depend entirely on the peculiar structure and functioning of the eustachian tube, a brief anatomic, normal physiologic, and special physiologic review of the latter structure will be presented first, followed by a discussion of the new clinical entity "aero-otitis media."

27. Anatomy.—*a. General.*—The eustachian tube is a slitlike, potential tube extending from the middle ear to the nasopharynx. It is formed of bone, cartilage, and fibrous tissue.

b. Bony portion.—The bony portion begins at the upper part of the anterior wall of the tympanic cavity and, gradually narrowing, passes downward, forward, and mediad for about 12 millimeters, ending at the angle of the junction of the squamous and petrous portions of the temporal bone.

c. Cartilaginous portion.—The cartilaginous portion of the tube extends from the bony portion to the nasopharynx. This section is about 24 millimeters in length and is formed of a triangular plate of elastic fibrocartilage with its apex attached to the bony portion and its base placed directly under the mucous membrance of the nasopharynx, where it forms a prominence, the torus tubarius. The upper edge of the cartilage is bent laterally and takes the form of a hook

on cross section, open below and laterally. These walls of the canal are completed by fibrous tissue.

d. Lumen.—The lumen of the eustachian tube is narrowest at the junction of the bony and cartilaginous portions, the isthmus, and expanding rapidly in both directions reaches its largest diameter at the pharyngeal orifice. At rest, the lumen of the cartilaginous portion of the tube is a vertical slit with its walls opposed.

e. Tissue.—The mucous membrane of the eustachian tube is a direct extension of that of the nasopharynx and continues backward to line the middle ear completely. The mucous membrane of the bony portion of the tube is thin, but in the cartilaginous portion it is thick and very vascular, contains numerous mucous glands and is composed of ciliated columnar cells. Near the mouth of the eustachian tube is a variable amount of adenoid tissue known as Gerlach's or tubal tonsil. The pharyngeal ostium of the eustachian tube is located high up on the lateral wall of the nasopharynx. This opening is triangular, bounded behind by the torus tubarius and in front by the nasal cavity.

f. Musculature.—The muscles that are attached to the eustachian tube and their actions are as follows:

(1) *Levator veli palatine.*—(*a*) *Origin.*—Inferior aspect of the pyramidis ossis temporalis and from the lateral end of the medial lamina of the eustachian tube.

(*b*) *Insertion.*—Downward medially and forward parallel to the inferior margin of the medial lamina of the eustachian tube, uniting in the soft palate with the corresponding muscle of the opposite side.

(*c*) *Action.*—Elevates the soft palate, narrows the eustachian ostium, and dilates the isthmus.

(2) *Tensor veli palatini.*—(*a*) *Origin.*—Scaphoid fossa of the sphenoid bone, lateral and membranous lamina of the eustachian tube, and angular spine of the sphenoid bone.

(*b*) *Insertion.*—The fibers run downward and forward around the sulcus of the pterygoid hamulus and, radiating mediad into the soft palate, attach to the hard palate and to the corresponding muscle of the opposite side.

(*c*) *Action.*—Tenses the soft palate and opens the eustachian tube.

(3) *Salpingopharyngeus.*—(*a*) *Origin.*—Inferior part of the ostium of the eustachian tube.

(*b*) *Insertion.*—Blends with the posterior fasciculus of the pharyngopalatinus muscle.

(*c*) *Action.*—Raises the upper and lateral parts of the pharynx; opens the ostium of the eustachian tube.

28. Physiology.—*a. Normal.*—The eustachian tube drains the middle ear and ventilates it. The motion of the cilia and the flutter-valve like action of the tube favors the motion of material from the ear to the nasopharynx and opposes motion in the opposite direction. The tube, while normally closed, is opened by contraction of its dilator muscles, and at such times any air pressure differential existing between the middle ear and the atmosphere is equalized. This contraction may occur during swallowing, yawning, and other similar physiologic acts.

b. Special.—(1) *Altitude-pressure relationship.*—Aircraft flights involve changes in altitude, and this in turn involves changes in atmospheric pressure, the relationship between the two being shown in figure 1. It is to be noted that, with ascent, equal changes of pressure in-

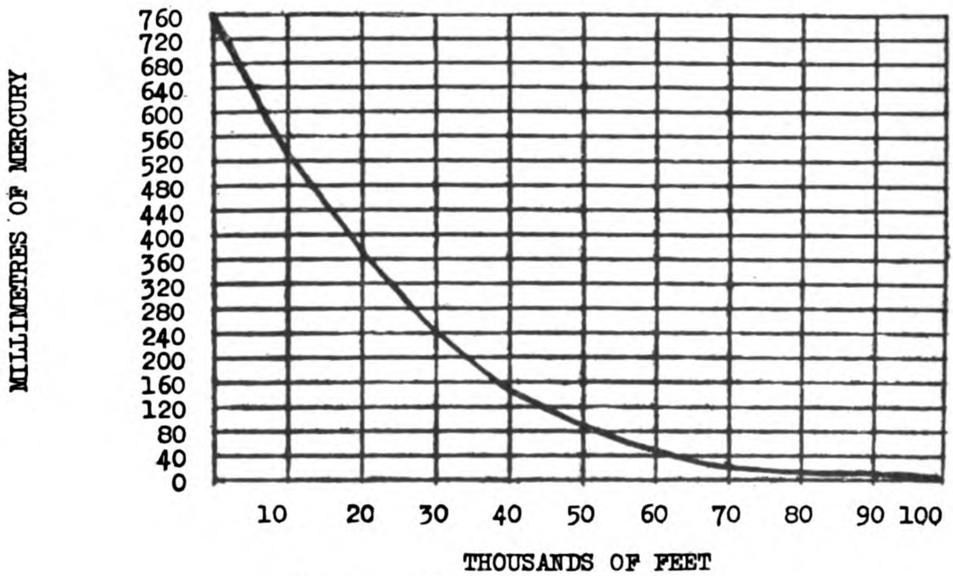

FIGURE 1.—Altitude-pressure curve.

volve increasing intervals of altitude. The rates and degrees of atmospheric pressure changes during flight depend on the rates and degrees of ascent or descent, and these factors become important when it is remembered that the ear is an air-filled, closed cavity with pressure equalization possible only when the eustachian tube is opened.

(2) *Results of laboratory investigations.*—Laboratory investigations of the physiology of the eustachian tube under marked variations of atmospheric pressure were carried out on five healthy men, pressure variation rates being from 5.4 to 27 millimeters of mercury per minute (200 to 1,000 feet per minute) through pressure ranges of from 760 to 141 millimeters of mercury (0 to 40,000 feet altitude). The results of this study were briefly as follows:

Beginning at sea level pressure and decreasing the pressure at a constant rate, a pressure change of from 3 to 5 millimeters of mercury (110 to 180 feet altitude) was required before any effect was perceptible in consciousness. At this point there appeared a slight sensation of fulness in the middle ears and examinations showed the tympanic membranes to be slightly bulged. This bulging and the sensation of fulness increased with the decreasing of pressure until at 15 millimeters of mercury (500 feet altitude) differential there was a sudden annoying "click" heard and felt in the middle ear, the drum snapped back to, or almost to, normal position, and the sensation of fulness disappeared. The eustachian tube had been forced open by the excess pressure in the tympanic cavity and the ear pressure relieved by a sudden rush of air from the ear to the nasopharynx.

During the remainder of the pressure decrease this cycle was repeated except that all succeeding "clicks" occurred at intervals of only 11.4 millimeters of mercury (435 feet altitude) pressure change. This indicated that it requires 15 millimeters of mercury excess pressure in the middle ear at sea level conditions to force the eustachian tube open and that it remains open until the pressure is reduced to about 3.6 millimeters of mercury, when it again closes, leaving 3.6 millimeters of mercury (130 feet altitude) excess pressure in the ear. It had been assumed that, since the pressure altitude curve is not a straight line (fig. 1), the eustachian tube would open at equal intervals of pressure but at increasing intervals of altitude during ascent. Actually the reverse was found to be true, the tubes opening at 425-foot intervals (except the first), which amounts to 11.4 millimeters of mercury pressure at sea level but only 3.5 millimeters at 40,000 feet. The explanation of this phenomenon is probably based on the fact that air of the higher altitudes, being less dense, passes more readily through the eustachian tubes. These figures are averages based on repeated tests. Actually there was considerable variation between individuals and in the same individual. These variations ranged from 5 to 30 millimeters at sea-level conditions, but the averages for individuals were remarkably constant.

When the atmospheric pressure was increased instead of decreased, a totally different effect was obtained. Here the eustachian tube, acting like a flutter-valve, remained closed under all degrees of pressure (one subject tested to −470 millimeters of mercury pressure) and the tympanic membrane finally ruptured.

In the course of these studies, swallowing and other voluntary efforts to open the eustachian tubes were suppressed. However, in a subsequent series of tests it was found that opening the eutachian tubes

by voluntary effort immediately equalized the ear pressure completely except that, after a negative pressure of from 80 to 90 millimeters of mercury or more had developed in the tympanic cavity, it was then impossible for the eustachian muscles to overcome the negative pressure which held the fibrocartilaginous portion of the eustachian tube tightly collapsed, and it was then necessary to decrease the atmospheric pressure below that point before the eustachian tubes could again be voluntarily opened.

29. Terminology.—Since the condition being discussed is already a recognized occupational disease and seems destined to become of general professional concern, it seems logical to suggest a proper terminology.

In the United States the term "aviator's or aviation ear" has begun to appear in the literature, while in Germany the terms "barotrauma" and "tonetrauma" have been suggested. The former are obviously unsuitable and the latter may be criticized as not being descriptive of the disease. We therefore suggest "aero-otitis media" (aero, combining form from the Greek *ἀήρ, ἀέρος*, air, + otic, Greek *ὠτικός*, pertaining to the ear, + itis, Greek *-ῖτις*, inflammation of) as suitable descriptive term for the new clinical entity about to be described, and that term will be used throughout the remainder of this paper.

30. Definition.—Aero-otitis media is an acute or chronic, traumatic inflammation of the middle ear caused by a pressure difference between the air in the tympanic cavity and that of the surrounding atmosphere, commonly occurring during changes of altitude in airplane flights and characterized by inflammation, discomfort, pain, tinnitus, and deafness.

31. Etiology.—Aero-otitis media is due to the lack of ventilation of the middle ear during changes of atmospheric pressure to the extent that the tympanic cavity is traumatized. There are two principal causes of improper middle ear ventilation: one a failure to open the eustachian tube voluntarily when necessary, the other the inability to open it.

Failure to open the eustachian tubes during changes in altitude in aircraft flights is most often due to ignorance of the necessity to do so but may be due to carelessness or to being asleep or may arise from the influence of analgesics or anesthetics or from coma. The first two of these instances usually occur among inexperienced pilots and passengers, the third in sleeper airplanes, and the last group on ambulance planes.

Inability to ventilate the middle ear voluntarily is much more prevalent than is generally recognized. Some of the most frequent causes of eustachian stenosis are acute and chronic infections of the upper respiratory tract, nasal obstructions, sinusitis, tonsillitis, tumors and growths of the nose and nasopharynx, paralysis of the soft palate or superior pharyngeal muscles, enlargement of the pharyngeal or tubal tonsil, inflammatory conditions of the eustachian tube or middle ear, scar tissue about the ostium of the eustachian tube following adenectomy, and malposition of the jaws.

The latter two conditions have but recently been recognized. Considerable scar tissue about the pharyngeal ostium of the eustachian tube sometimes occurs as the result of adenectomy when the adenotome had been allowed to pass too far laterally, causing trauma or laceration to the torus tubarius.

The effect of malposition of the mandible in relation to stenosis of the eustachian tube was first reported by Costen[1] and later applied to aviation by Willhelmy.[2] They showed that in individuals with edentulous mouths, ill-fitting dental plates, marked overbite, malocclusion, worn or lack of molar teeth either unilateral or bilateral or with any other condition in which there was a shortening of the vertical position of the lower jaw a compression-stenosis of the eustachian tube was likely to occur from a relaxation of the surrounding soft tissues.

32. Symptomatology.—The symptoms of aero-otitis media depend on the duration, frequency, and severity of the trauma sustained.

a. Aero-otitis media, acute.—(1) *Subjective symptoms.*—Positive pressures of from 3 to 5 millimeters of mercury in the middle ear are perceptible in consciousness to most individuals as a feeling of fullness in the middle ear. At about 10 to 15 millimeters of mercury pressure the feeling of fulness is distinct and somewhat annoying and affects the hearing by imparting a distant sound and a lessened intensity. Pressures between 15 and 30 millimeters of mercury usually increase the discomfort and may be accompanied by tinnitus. The latter is of a steady hissing or roaring character or crackling and snapping. In some individuals there may be actual pain and vertigo of a mild nature. Above 30 millimeters of mercury pressure in the middle ear there is increasing pain, tinnitus and vertigo, which finally becomes unbearable.

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[1] J. B. Costen, "A Syndrome of Ear and Sinus Symptoms Dependent upon Disturbed Function of the Temporomandibular Joint," *Annals of Otology, Rhinology, and Laryngology*, 43 : 1 (March), 1934.

[2] G. E. Willhelmy, "Ear Symptoms Incidental to Sudden Altitude Changes and the Factor of Overclosure of the Mandible: Preliminary Report," *United States Naval Medical Bulletin*, 34 : 533-541 (Oct.), 1936.

In normal cases about 15 millimeters of pressure is sufficient to force air out through the eustachian tube, which relieves the pressure in the tympanic cavity and consequently the accompanying symptoms. However, this relief is initiated by an annoying "click," which is both felt and heard as the drum snaps back to normal position. In stenosis of the tube the pressure required to force it open varies with the degree of stenosis. In these cases the pressure may be relieved gradually over a period of time instead of instantaneously, and a greater amount of pressure remains in the middle ear after the tube has again closed.

In descent, in which the atmospheric pressure is increasing and the pressure in the ear becomes negative, the symptoms are the same as already described except that the pressure is never relieved through its own force acting on the eustachian tube because of the flapper-valve like action of the latter. For this reason the greatest difficulty usually occurs during descent in aircraft, and the highest pressure differentials have been seen and studied experimentally under this condition. At about 60 millimeters of mercury negative pressure the pain in the ear is severe and resembles that of acute otitis media. The tinnitus is marked and there is usually vertigo with beginning nausea. At from 60 to 80 millimeters of mercury negative pressure the pain is very severe and radiates from the ear to the temporal region, the parotid gland, and the cheek. Still higher pressures produce agonizing pain, which seems to localize not in the ear but deep in the substance of the parotid gland. Deafness is marked and vertigo and tinnitus usually increase, but the latter may disappear. At between 100 and 500 millimeters of mercury pressure the tympanic membrane ruptures.

This occurrence is a dramatic episode in which the patient feels "as though hit along the side of the head with a plank," a loud explosive report is felt and heard in the affected ear, there is a sharp piercing pain on the affected side, vertigo and nausea become marked, and collapse or generalized shock follows. With rupture of the tympanic membrane the acute pain quickly subsides, but a dull ache persists for from 12 to 48 hours. Hearing is distinctly diminished and vertigo and nausea may persist for from 6 to 24 hours.

With both positive and negative pressures, voluntarily opening the eustachian tube will immediately relieve all acute symptoms; but it is to be remembered that with a negative pressure in excess of about 80 or 90 millimeters it becomes impossible to overcome this by muscular action, and relief is obtained only by a return to a higher altitude and a pressure difference of less than from 80 to 90 millimeters of mercury. In cases in which the pressure has already produced

trauma, opening the eustachian tube will not relieve the symptoms of that trauma, and they persist until recovery has taken place. The symptoms following trauma to the middle ear depend on the extent and duration of the trauma. Pressures that may be only uncomfortable at first finally become painful. Moderate trauma to the ear is followed by a sense of soreness in the ears and deafness lasting from 1 to 12 hours. Severe trauma is followed by pain, deafness, vertigo, and tinnitus for from 4 to 48 hours. The pain is similar to that of suppurative otitis media, the tinnitus usually of a hissing or roaring character, the deafness of the conduction type, and qualitative as well as quantitative.

(2) *Objective symptoms.*—The objective signs depend on the amount of trauma sustained. In mild cases the drum may appear normal except for a moderate degree of bulging or retraction when a small amount of pressure differential still persists. An increased pressure in the tympanic cavity is denoted by a bulging of the tympanic membrane with a decrease or loss of the light reflex.

A negative pressure in the tympanic cavity is denoted by a retraction of the tympanic membrane with a decrease in size and brilliance of the light reflex and an increased prominence of the short process of the malleus with a foreshortened and more horizontal handle.

Following more severe trauma, the drum may be retracted or bulging as already described, and in addition there is also an inflammation, which in appearance varies from a slight pink tinge to an angry red. In all cases the inflammation is most marked along the larger vessels that follow the malleus handle and around the drum periphery. When the inflammation is severe it cannot be distinguished from acute infectious otitis media and has frequently been mistaken for it.

Traumatic ruptures of the tympanic membrane are usually linear and quite extensive and may involve any portion of it. The margins of fresh ruptures are red and the whole drum is highly inflamed. There is usually a small amount of blood in the external auditory canal. If the labyrinthic wall is visible through the freshly ruptured drum membrane, it is seen to be red, congested, and swollen.

Audiometer tests shown a variable diminution of hearing, depending on the severity of the injury.

b. Aero-otitis media, chronic.—(1) *Subjective symptoms.*—In these cases there is a "full and stuffy" feeling in the ears and difficulty in "clearing" them. There is a partial loss of hearing, which is either unilateral or more pronounced on one side and in some instances may vary from day to day. Head noises may be present, but rarely ver-

tigo or pain. The condition is worse after flights, during acute infections of the upper respiratory tract, during changes of weather, and during fatigue or debilitated states.

(2) *Objective symptoms.*—The eardrums are bulging or retracted, usually the latter. The drum membrane is dull, lusterless, and slightly thickened and the light reflex is diminished or absent. Hearing acuity is diminished either unilaterally or bilaterally, and in the latter case there is usually a considerable difference between the two sides. This deafness is of the conduction type, the lower tones of the scale being lost first. Rinne's test is negative. Weber's test is positive and bone conduction is prolonged beyond the normal. Examination of the ostium of the eustachian tube shows the presence of a chronic inflammatory process or a mechanical obstruction.

33. Diagnosis.—The diagnosis of aero-otitis media is simple only if the history is known. The different traumatic inflammatory stages closely resemble the various stages of infectious otitis media and, as previously stated, have frequently been mistaken for it. Likewise, chronic aero-otitis media may be easily mistaken for a chronic infectious middle ear process unless a history of exposure to repeated changes of altitude is obtained.

34. Complications.—While trained pilots usually try to avoid flying during periods when they have an acute infection of the upper respiratory tract, because of the discomfort and pain in the ears which almost invariably occurs, nevertheless a considerable amount of such flying has been done. It might naturally be expected in these cases that during descent the intermittent blasts of air from the pharynx to the tympanic cavity would carry with it septic material to the mechanically irritated tympanum and readily set up an acute inflammatory process. While it is possible or even probable that this septic material is carried into the tympanus there are no reports of such cases.

35. Treatment.—*a. Prophylaxis.*—Those who take up aviation as a profession are, and should continue to be, carefully tested for patency of the eustachian tubes. This may readily be done by means of the Politzer bag. Those who have a stenosis of the tube should be examined for chronic infection of the ear, sinuses, nose, and pharynx, the mouth of the tube inspected for mechanical obstructions, and the eustachian tube catheterized, if necessary. When any of these conditions are found and corrected, it is likely that the tube will become normal. Persons examined during periods of an acute infection of the upper respiratory tract should be reexamined after the infection has subsided before a final decision is made.

Probably the most useful prophylactic measure in all cases is proper instruction of the individual concerned. As long as the patency of the eustachian tube is under voluntary control there is no reason why any person in command of his faculties need experience difficulty at any rate of ascent or descent possible in present commercial aircraft. A simple explanation of the functioning of the eustachian tube followed by instructions as to how to ventilate the tympanus, when to ventilate it, and how frequently this is necessary should suffice. Probably the simplest maneuver to actuate the normal eustachian tube is to swallow. It may also be accomplished by yawning, by singing, by shouting, by autoinflation, and by contracting the salpingopharyngeal muscles. The last named defies description and can be learned only by practicing the suppression of a simulated yawn, at which time a roaring in the ears will indicate when the effort is successful.

Since the average person swallows involuntarily about every 60 to 75 seconds, it can be seen that a rate of climb or descent of 200 feet per minute will usually cause no discomfort, 500 feet per minute slight discomfort, and 1,000 feet per minute moderate discomfort even though no effort is made to ventilate the tympanum artificially. Descents above 4,000 feet per minute may catch an individual unaware and create a tympanic vacuum which it is impossible to relieve by any method except a return to higher altitudes.

Chewing gum, eating, drinking, or inhaling oxygen reduces swallowing to intervals of from 1 to 30 seconds. Sleeping and comatose individuals swallow at increased intervals and present a serious problem.

The allowable rate of ascent and descent of commercial air lines is set by the Department of Commerce at 300 feet per minute, and some such companies limit themselves to 200 feet per minute, although unusual conditions such as weather may require that both of these rates be exceeded to insure the safety of the flight. Those who are suffering from either temporary or permanent stenosis of the eustachian tube should be enjoined from flying except under controlled conditions of gradual changes of altitude through a maximum range not to exceed 2,000 feet. Those with an acute infection of the upper respiratory tract who insist on aerial flights should be prepared by gargling hot physiologic solution of sodium chloride or by having a detergent spray directed well back into the nasopharnyx followed by the instillation or inhalation of atrophine, ephedrine, or benzedrine compounds.

b. Active treatment.—Relief of pain is the first consideration in acute cases. The tympanum should be gently inflated by Politzer's method if the drum indicates the existence of either positive or negative pressure. Heat, dry or wet, is very effective. The installation

of copious quantities of water into the external auditory canal at from 110° to 115° F., followed by dry heat is the method of choice. Inflammation of the ostium of the eustachian tube requires treatment, and hot saline gargles followed by the instilling or mopping of astringents over that area will shorten the period of discomfort. In severe cases analgesics and even the injection of morphine, from one-eighth to one-fourth grain (0.008 to 0.016 gm.), may be necessary for the first 24 hours.

c. *After-treatment*.—The after-treatment consists of the application of dry heat to the ear and the inhalation or instillation of astringents into the nasopharynx every 4 hours. A plug of cotton in the external canal seems to add to the comfort, especially during cold weather.

If the condition does not subside materially in 24 hours, acute infectious disease of the middle ear should be suspected or a stenosis of the eustachian tube looked for and corrected.

Ruptures of the tympanic membrane should be left alone and treated expectantly.

In chronic aero-otitis media, stenosis of the eustachian tube should be looked for and treatment directed to its relief. Chronic infections of the ear, tonsils, sinuses, nose, and pharynx should be considered as possible causative factors and corrected. Mechanical obstruction of the eustachian ostium or tube should be removed. If there is no apparent infection and no obvious obstruction of the tube, a malposition of the lower jaw with compression of the tube may be assumed and the jaw temporarily repositioned by the technic of Willhelmy[8] for clinical test and, if successful, permanent measures applied.

The eustachian stenosis having been relieved, the chronic inflammatory process in the tube and middle ear usually subsides spontaneously, but this may be hastened by gentle inflation of the ear or, if the congestion is marked, by the application of heat to the external ear and nasopharynx. Until the condition is entirely relieved, flying should be avoided as a potential source of irritation.

36. Pathology.—In acute cases the first change is a passive hyperemia of the mucous membrane of the middle ear and eustachian tube from negative pressures or an ischemia from positive pressures. On relief of the pressure in either case there follows a period of active hyperemia, the degree and duration depending on the severity and duration of the trauma. With high pressures actual traumatic inflammation takes place accompanied by a serous exudate. The

[8] *Ibid.*

mucous membrane becomes congested and swollen, the eustachian tube blocked, and the tympanic cavity a closed cavity. The epidermal layer of the tympanic membrane takes part in the reaction and becomes inflamed and may rupture.

Chronic aero-otitis media depends on frequently repeated insults to the tympanic cavity in which the tympanic membrane and the mucous membrane of the middle ear and of the eustachian tube become chronically congested and thickened.

The pain in aero-otitis media is not merely local. In severe cases it may reflexly or directly affect the facial nerve and its branches and thus produce a neuralgic-like pain which radiates over the distribution of that nerve.

37. Summary.—A new clinical entity is presented which consists of a traumatic inflammation of the middle ear caused by a pressure difference between the air in the tympanic cavity and that of the surrounding atmosphere, commonly occurring during changes of altitude in airplane flights and characterized by inflammation, discomfort, pain, tinnitus, and deafness.

Section VI

ANATOMY AND PHYSIOLOGY OF INNER EAR OR LABYRINTH

38. Osseous labyrinth.—Two distinct mechanisms are to be considered as comprising the inner ear or labyrinth.

a. The *cochlea*, the essential organ of hearing.

b. The *vestibular apparatus*, a contributory organ of equilibrium or orientation consisting of the saccule, utricle, and three semicircular canals.

These structures are contained within a series of little communicating cavities located within the petrous portion of the temporal bone and known as the *osseous labyrinth.* Within the cavities of the bony labyrinth and surrounded by a supporting fluid, the *perilymph*, is the essential structure known as the *membranous labyrinth*, the cavity of which is filled with *endolymph.*

c. Anatomically the osseous labyrinth is divided into three main portions, a central cavity, the *vestibule;* an anterior portion, the

cochlea; and a posterior portion, the *semicircular canals.* The vestibule lies internal to the middle ear and but for the foot plate of the stapes would communicate with it by means of the oval window. Anteriorly it communicates with the cochlea and posteriorly with the semicircular canals.

(1) *Vestibule.*—The oval window of the middle ear opens into the vestibule and marks the center of its outer wall. It measures 5 or 6 millimeters from before backward and approximately 4 millimeters each in width and height. On the inner vestibular wall, nearer the anterior than the posterior wall, is a slight ridge, approximately vertical, the *crista vestibuli.* In front of this is the *recessus sphericus,* which lodges the *saccule,* while behind is the *recessus ellipticus,* which lodges the upper part of the *utricle.* There are eight openings into the vestibule, as follows:

(*a*) Five openings for the three semicircular canals. The ampullar ends of the horizontal and anterior vertical enter the vestibule through the roof, above the oval window. The ampulla of the posterior vertical canal is in the floor. Behind this, that is, in the posterior wall near the roof, is the opening of the small end of the horizontal canal. The common opening of the anterior and posterior canals is near the angle formed by the inner and posterior walls with the roof.

(*b*) Opening of the scala vestibuli of the cochlea in the anterior and outer corner.

(*c*) Aqueductus vestibuli. On the inner wall.

(*d*) Maculae cribosae. Small openings in the crista vestibuli, recessus sphericus, and recessus ellipticus. These give passage to sacular and utricular branches of the vestibular nerve.

(2) *Cochlea.*—The cochlea is a bony tube about 1½ inches in length having two and one-half coils about a central core, the *modiolus,* the coils resembling a snail. The diameter of the tube near the vestibular end is about 2 millimeters, this calibre rapidly diminishing after the first turn to about 1 millimeter. From the center of the base to the apex, its axis lies in a horizontal plane and is directed forward and outward. The lamina spiralis, a bony projection, passes outward from the modiolus into the lumen of the spiral canal and extends about halfway across the cochlear tube. The *basilar membrane* extends from the outer edge of the lamina spiralis to the outer edge of the cochlear tube, dividing it into two channels, an inner, communicating with the middle ear through the round window, and known as the *scala tympani,* and an outer, opening into the vestibule, known as the *scala vestibuli.* These two cavities communicate with each other at the apex of the pyramid, the *helicotrema.* On the floor of the scala tympani near its beginning at the round window is the *aquaductus cochleae,* a small,

short canal, leading to the basal surface of the skull near the jugular foramen. The membranous canal, however, is continued inward and perforates the dura to communicate directly with the subarachnoid space.

The cochlear branches of the auditory nerve pass through the core of the modiolus to reach by minute openings the osseous lamina spiralis and thence to the basilar membrane and organ of Corti.

(3) *Semicircular canals*—(*a*) *Number.*—The semicircular canals are three in number, horizontal, anterior vertical, and posterior vertical.

(*b*) *Description.*—Each semicircular canal comprises about two-thirds of the circumference of a circle, the diameter of which is 7 to 8 millimeters. They are elliptical on cross section and each canal has a slight enlargement at one end, called the *ampulla.* The canals are a little over 1 millimeter in diameter, except at the ampullae where they are 2½ millimeters in diameter. Both ends of each semicircular canal open into the vestibule. The narrow ends of the anterior vertical and posterior vertical join before they reach the vestibule into which they open by means of a common limb. The ampulla of the anterior canal lies at its outer end. The ampulla of the horizontal canal lies at its anterior end. The ampulla of the posterior canal lies at its lower end. The ampullated ends of all three canals lie nearer to the middle ear than do the small ends, also all are the more anterior ends.

The middle portion of the horizontal canal lies exposed in the attic and aditus. It forms a prominence on the inner wall of the attic and aditus, lying just above and behind the facial nerve, and here suppurative processes in the middle ear frequently cause erosions and, as a matter of fact, this is the most common situation for a labyrinthine fistula. The horizontal canal is a guide in the simple mastoid operation, exposure of same indicating that the aditus has been reached. In the radical mastoid it indicates the limit to which the posterior wall of the external auditory meatus may be taken down without injury to the facial nerve.

(*c*) *Position.*—With head erect and chin drawn inward, the horizontal or external lies very nearly in a horizontal plane. The other two are both vertical, the anterior vertical lying in a vertical plane directed from within outward and forward, and the posterior vertical occupying a vertical plane at right angles with that of the anterior vertical, that is, outward and backward. It is obvious that each canal lies in a plane at right angles to the other two. The posterior vertical is on a much lower plane than the anterior vertical.

It has been noted from a large number of corrosion specimens that the planes of the canals, as well as the angles between them, are very inconstant. The horizontal canal is rarely horizontal. Its plane is tilted downward and backward and forms with the horizontal plane an angle varying from 0° to 30°. This fact is important in interpreting the results of functional examination of the static labyrinth. The angle which the plane of the anterior vertical canal makes with the medial plane, varies between 30° and 65°. There may be a difference of 20° between the right and left sides. The angle between the anterior vertical and horizontal canals varies between 65° and 90°. The angle between the horizontal and inferior vertical canals is most constant, varying from 90° to 100° and being usually 90°.

The anterior vertical canal of the right side is parallel to the posterior vertical of the left side, and the anterior vertical of the left side is parallel to the posterior vertical of the right side.

39. Membranous labyrinth.—*a. General.*—The membranous labyrinth consists of—

(1) The membranous vestibule, which is divided into the saccule and the utricle.

(2) Three membranous semicircular canals, namely, horizontal, anterior vertical, and posterior vertical.

(3) The membranous cochlea.

The membranous labyrinth is partly surrounded by a supporting fluid, the Perilymph, partly because in most regions it is connected at some points with the endosteum lining the walls of the osseous labyrinth. On account of the perilymph separating it, in many places, from the osseous canal, it is necessarily smaller than the osseous portion. Wherever the labyrinth filaments of the auditory nerve perforate the bony capsule to reach the membranous labyrinth, the membranous parts so supplied are attached to the bony surface thus perforated, for example, cristae acusticae of the ampullae and the maculae acusticae of the utricle and saccule.

The perilymph space communicates with the subarachnoid space of the skull through the aquaductus cochleae, which opens on the basilar surface of the petrous portion of the temporal bone, internal to the jugular fossa. The cavities and canals of the membranous labyrinth are filled with endolymph. The endolymph space does not communicate with the subarachnoid space of the skull as is the case with the perilymph space.

b. Membranous vestibule.—The membranous vestibule consists of the saccule, in the recessus sphericus, and the utricle, in recessus ellipticus.

(1) *Saccule.*—The saccule communicates with the scala vestibulae and scala media (ductus cochlearis) of the cochlea through the canalis reuniens and only indirectly with the utricle. It lies in front of the crista vestibuli, being partly separated from the utricle by this ridge. The recessus sphericus and the anterior surface of the crista vestibuli present numerous small perforations through which the saccular branches of the vestibular nerve pass. Penetrating the contiguous surface of the saccule, they present a circumscribed bulging of the inner wall known as the macula acustica. The canal reuniens, a membranous canal, passes downward from the lower part to enter the ductus cochlearis of the cochlea. Another small canal from the posterior part passes downward and backward to unite with a similar canal from the utricle, aquaductus vestibuli, or aqueduct of the endolymph. This is the only communication between the saccule and utricle.

(2) *Utricle.*—The utricle, about 5 millimeters in length, is attached to the posterior part of the inner wall of the bony vestibule. Its upper half is lodged in the recessus ellipticus, behind the crista vestibuli. The portion resting against the recessus ellipticus, the recessus utriculi, is perforated by numerous small foramina for the passage of the utricular branches of the vestibular nerve forming on its inner wall a circumscribed bulging which is the highly specialized neuro-epithelial end-organ, the macula acustica.

The cavity of the utricle communicates by five openings with the three semicircular canals. The ampullar ends of the horizontal and anterior vertical open on its roof, the ampullar end of the posterior vertical perforates its floor, and the opening of the small end of the horizontal canal and the common opening of the two vertical canals enter the posterior wall. From the lower end of the utricle a small membranous tube passes forward, inward, and downward. This unites with a similar tube from the saccule to form the aquaductus vestibuli. The aquaductus vestibuli enters a small bony opening on the inner wall of the bony vestibule and traverses the bone in a curved direction inward and somewhat backward to emerge by a slit-like opening upon the posterior surface of the petrous portion of the temporal bone, seven-eights millimeter behind the internal auditory meatus. It here expands into a closed sac, the saccus endolymphoaticus, with no direct communication with the cerebrospinal channels or subarachnoid space. The perilymph, as previously stated, escapes through the aquaductus cochlea to mingle directly with the cerebrospinal fluid.

c. Membranous semicircular canals.—(1) Membranous semicircular canals are elliptical on transverse section and are attached to the

greater circumference of the bony tubes. The peripheral portion of the ellipse is fixed to the periosteal lining of the bony canal, while the opposite part is free, except that it is connected by irregular bands, the ligament labyrinthi canaliculorum, which pass through the perilymph space to the bony wall. Like the bony canals, each membranous canal is dilated at one extremity into an ampulla, which is especially developed toward the concave aspect of the tube. While the membranous ampullae nearly fill the corresponding portions of the bony tubes, the calibre of the remaining parts of the membranous canals is equal to only about one-fourth of that of the osseous canals.

(2) *Histology*.—Histologically there is a great similarity in the membranous semicircular canals, the utricle, and the saccule. They are composed of three layers, an outer fibrous layer, a delicate basal membrane, and a single layer of squamous epithelial cells. The fibrous layer is similar to the periosteum lining the bony canals and vestibule with which it is continuous, at the points where the membranous canals are attached to the bone. The basal membrane is homogeneous and very thin. This as well as the connective tissue layer becomes thicker at the maculae and cristae. As we approach the maculae and cristae the squamous epithelium becomes columnar and in the end organs changes into ciliated neuro-epithelium.

(3) Overhanging the ciliated neuro-epithelial cells is a structure containing a mass of minute crystalline grains of carbonate of lime imbedded in a gelatinous substance. This structure is known as the otolith membrane where it overhangs the maculae acusticae in the vestibule and as the cupula where it overhangs the cristae acusticae in the semicircular canals. It is claimed by some authors that the otolith membrane and the cupula are attached to, or are a part of, the walls of the vestibule and semicircular canals, opposite the neuro-epithelial cells and is not a free membrane.

d. Membranous cochlea.—(1) The membranous cochlea consists of—

(*a*) Basilar membrane.
(*b*) Reissner's membrane.
(*c*) Spiral organ of Corti.
(*d*) Membrana tectoria.

(2) These structures divided the cochlear tube into four lesser tubes or canals as follows:

(*a*) Scala tympani.
(*b*) Scala vestibuli.
(*c*) Scala media or ductus cochlearis.
(*d*) Canal of Corti.

(3) As previously stated, the basilar membrane extends from the apex of the lamina spiralis to the opposite wall of the cochlear tube, thereby dividing this tube into two main canals, the scala tympani and scala vestibuli. Reissner's membrane originates near the apex of the lamina spiralis on the vestibular side, and extends upward and outward to become attached to the opposite cochlear wall. This membrane forms an additional canal within the scala vestibuli, the scala media or ductus cochlearis, and it is in this canal that the essential organ of hearing, the *spiral organ of Corti*, is located. The scala media and the scala vestibulae communicate with the saccule through the ductus reuniens. The scala tympani extends to the round window in the inner wall of the middle ear with which it would communicate except for a thin membrane which covers this opening.

(4) *Spiral organ of Corti.*—The spiral organ of Corti is the essential end-organ of hearing and is located in the scala media and extends the entire length of this canal. It is composed of a series of epithelial structures and appears as a small elevation upon the basilar membrane. The more central of these epithelial structures are two rows of rod-like bodies, the inner and outer rods of Corti. The bases of these rods rest upon the basilar membrane, and the two rows are some distance apart. The rods are inclined toward each other and the free ends come in contact above, thus forming a minute tunnel, the canal or tunnel of Corti. On the medial side of the inner rods is a single row of short columnar epithelial cells, the inner hair cells, the upper ends of which are on a level with the upper extremities of the rods and extend about halfway down to the basilar membrane. Each columnar cell is surmounted by twenty to thirty hair-like processes, arranged in the form of a crescent. These hair cells are supported by two or three rows of columnar epithelial cells.

On the lateral side of the outer rods of Corti are two to three rows of columnar cells, similar to the inner hair cells, but somewhat longer and surmounted in the same manner by hair-like processes, the outer hair cells. Between the outer hair cells are rows of supporting cells with expanded bases terminating in phalangeal-like processes, known as the cells of Dieters. Overhanging the inner and outer hair cells, but not touching them while in a position of rest, is a membrane of irregular thickness attached to the vestibular side of the lamina spiralis, near the origin of Reissner's membrane, known as the *membrana tectoria.* This membrane is composed of a multitude of delicate fibers imbedded in a transparent matrix of marked adhesiveness.

40. Cochlear and vestibular branches of auditory nerve.—The cochlear branches of the auditory nerve enter the cochlea by

minute perforations in a circular depression at the base of the modiolus. They traverse this to reach the base or outer margin of the lamina spiralis, where they form bipolar ganglion cells, the *spiral ganglion* or *ganglion of Corti.* From this ganglion the fibers radiate outward between the plates of the lamina spiralis and perforate its outer plate to reach the basilar membrane and the organ of Corti, where they arborize around the hair cells.

The distribution of the vestibular branch of the auditory nerve has been mentioned in the description of the membranous vestibule. In the internal auditory meatus the vestibular portion of the nerve divides into an upper branch which supplies the utricle and ampullae of the horizontal and anterior vertical canals and a lower which supplies the saccule and ampulla of the posterior vertical canal.

Within the auditory meatus the cochlear and the vestibular branches are traced to their common trunk which passes inward across the subarachnoid space to the restiform body in the medulla. The nerve, according to Dana, enters the medulla by two roots, a lateral or a posterior root composed chiefly of auditory fibers and a median root composed chiefly of vestibular fibers. These roots communicate with three nuclei, namely—

a. A central, the acustic tubercle on the floor of the fourth ventrical.

b. The ventral or accessory nucleus, springing from the lateral root and lying between it and the median root.

c. A large-celled nucleus (Deiters' nucleus) which lies external to and below the central nucleus.

The lateral or auditory root communicates chiefly with the accessory nucleus, but also with the other nuclei. From the central and accessory nuclei auditory fibers are sent to the temporal lobes of both hemispheres, but more to the opposite than to the corresponding side. The cortical centers for hearing are in the first and second convolutions of the temporal lobes. Owing to the above distribution of the auditory nerve fibers, destruction of the cortical center on one side will result in impairment of function of both ears, but the impairment will be greater in the ear opposite to the side on which the destruction occurs.

The median root is composed chiefly of vestibular fibers and connects principally with Deiters' nucleus and through this to the cerebellum.

41. Special sense organs of inner ear.—*a.* The following three types of special sense organs are located within the inner ear:

Macula acustica (two in number).
Christa acustica (three in number).
Spiral organ of Corti.

(1) One of the maculae acusticae is located in the saccule on the anterior surface of the christa vestibuli and recessus sphericus, the other in the utricle behind the crista vestibuli in the recessus elipticus. Both maculae occur as irregularly round or oval elevations which project from the inner walls into the cavities of the saccule and utricle.

(2) The cristae acusticae are located one in each of the ampullar ends of the semicircular canals and are similar in appearance to the maculae.

(3) The spiral organ of Corti is located in the scala media (ductus cochlearis) of the cochlea. It rests upon the basilar membrane and appears as a small elevation extending the entire length of the cochlear tube.

b. These three types of end-organs appear superficially quite different, but when examined closely are found to be fundamentally alike in many respects. In each end-organ the important physiological element is a peculiar hair-bearing cell which receives the terminal filaments of the eighth nerve, and in which the transference of a physical to a nervous impulse takes place. In each end-organ, moreover, there is a peculiar structure of epithelial origin which overhangs the hair cells and with the under surface of which in each instance the hairs of the hair cells come in contact. In the maculae acusticae this structure is known as the otolith membrane, in the cristae acusticae it is known as the cupula, and in the spiral organ of Corti it is known as membrana tectoria.

42. Physiology of vestibule and semicircular canals.—That the vestibular apparatus is not an organ essential to equilibrium has been definitely shown, in that after complete ablation of the organs, equilibrium is soon reestablished.

It is highly probable that the vestibular mechanisms are in one sense organs of orientation, in that they enable man under all conditions (on the ground), that is, in light or darkness and in whatever position the body may be placed, subconsciously and without effort to determine the position of the different parts of his body. It is the sudden withdrawal of this power which places the individual, after removal of the labyrinths, in some danger of serious accident, even after he has recovered from the first vestibular disturbances incident to the operation. That he soon learns to guard against such mishaps under all or any conditions does not disprove the value of these organs in health. It proves simply that certain other faculties, for example, the so-called muscle, arthrodial, and tactile senses and the sense of sight, have so enlarged their scope as to compensate for that which he has lost.

Whatever the exact function may be, it is fairly certain that the essential structures are the end-organs in the cochlea, vestibule, and semicircular canals. Both histologically and physiologically they are similar. Thus, both the organ of Corti and the cristae and maculae acusticae are covered by a highly organized neuro-epithelium, of which the surface strata are composed of cells from which hair-processes project. On each of these organs the hair-processes project into an important superimposed structure, friction or impact against which is essential to its proper performance of function. Thus the hair cells of the cristae acusticae do not project directly into the endolymph of the ampullae, but into the soft cupula overhanging them. The hair cells of the maculae acusticae are in contact with the otolith membrane, while the hair cells of Corti's organ project toward the under surface of the tectorial membrane. According to one authority, the relation of the free surface of the organ of Corti and tectorial membrane is one of actual contact, impact of the hair processes with the membrane is brought about through the agency of the sound waves propagated through the labyrinthine fluids. In the case of the cristae and maculae acusticae, interaction is brought about by sudden changes in the position of the head.

In health, it is probable that the various parts of the vestibular apparatus act in concert, injury to any one canal causes subjective and objective symptoms similar to those following injury of the other two, or to the parts resting within the bony vestibule.

One theory considers a threefold function:

a. Acoustic.—Located in the cochlea.

b. Static.—Located in the saccule and utricle.

c. Kinetic.—Located in the semicircular canals and the utricle and saccule.

It is believed that wave impulses in the external ear cause a movement of the drumhead; those impulses are carried mainly by the chain of ossicles through the footplate of the stapes, which vibrates in the oval window, causing similar movements in the endolymph; these in turn impinge upon the hairs of the organ of Corti. In bone conduction, the stimulation is more directly through the endolymph, both producing the appreciation of sound, originating in the external world. In contrast to this, the hair cells of the kinetic labyrinth are usually set in motion by movements of the body itself.

When the body is at rest the otoliths by their pressure on the maculae of the saccule and utricle give information as to the position of the body; this is the static function. The kinetic function is dependent upon the entire equilibratory portion of the ear; the three

semicircular canals take cognizance of rotary movements of the body in all conceivable planes. Movements in a linear direction, anterior-posteriorly, are probably detected by the macula of the utricle; linear movements in a lateral direction are detected by the macula of the saccule; and linear movements in a vertical direction, up and down, are detected by both utricle and saccule.

If the body moves forward in a linear direction there results a lagging behind of the otoliths above the macula of the utricle. If sideways there is a lagging behind of the otoliths above the macula of the saccule. If there is a rotary movement there results a movement of the endolymph in one or more of the semicircular canals, thereby affecting certain of the hairs in the corresponding crista or cristae. When the current is toward the ampulla, the hairs of that side are put upon the stretch; if the current is away from the ampulla the hairs of the opposite side are put upon the stretch. The hair cells of the two sides of the crista are connected by separate nerve fibers with different central nuclei and because of this arrangement it is possible for the cells of one side of the crista to produce diametrically opposite phenomenon. A current toward the ampulla in the horizontal canal produces twice as strong a reaction as a current away from it, while in the vertical canals the current away from the ampullae produces twice as strong a reaction as a current toward the ampulla and here the two canals act together.

The entire labyrinthine cavity is considered by some authorities as an irregularly shaped vessel containing fluid, the perilymph, and within the membranous labyrinth the endolymph, all having the temperature of the blood. In douching test the hot or cold water in contact with a part of the wall causes either a rise or fall in the temperature at that point and a consequent rise or fall in the fluid. Since the anterior half of the horizontal canal and the anterior or outer third and ampulla of the anterior vertical canals are nearest the tympanic surface, these parts are first influenced by rise or fall in temperature. In rotation experiments, there is at first a lagging behind of the endolymph, then the endolymph moves as rapidly as the subject being rotated and when rotation suddenly ceases, the endolymph continues moving in the direction toward which the subject has been turned.

That an endolymph movement takes place is clearly shown by the following: Incline the head backward 60°; this puts the horizontal canal in the vertical position. Douching the right ear with cold water then produces—

Horizontal nystagmus to left.
Sensation of rolling to left.

Past-pointing to the right.
A rolling or falling to right.

Now without further douching tilt the head forward 120°, which puts the horizontal canal in the vertical plane, but exactly upside down from the previous position; there immediately appears—

Horizontal nystagmus to right.
Sensation of rolling to right.
Past-pointing to the left.
A rolling or falling to left.

43. Cochlea.—*a.* If the three structures present in the scala media, that is, the organ of Corti, the supporting basilar membrane, and the superimposed membrana tectoria are regarded as constituent parts of one mechanism, and it is assumed that sound waves transmitted through the cochlear perilymph will impress certain fibers in this mechanism and thereby induce auditory impressions of tone varying with the vibration rapidity, the common belief of otologists shall have stated.

b. One authority believes the basilar membrane to be the essential structure. A later view holds that the different tones in the scale affect certain definite parts of the tectorial membrane by vibration, accomplishing in this way a stimulation of a different group of hair cells for each particular tone. The impulse is transmitted directly from the scala vestibuli through Reissner's membrane to the tectorial membrane and as this lies directly over the hair cells, the movement is imparted to the hairs. This theory brings the action of the end-organ in the cochlea into harmony with the action of the end-organs in the vestibule and semicircular canals. The otolith membrane in the vestibule, the cupula in the ampullae of the semicircular canals, and the tectorial membrane in the organ of Corti all overlie hair cells.

c. Telephone theory.—In this it is assumed that the entire basilar membrane vibrates with every tone as the receiver of a telephone; analysis of the sound takes place in the brain.

d. In an article "How Does the Organ of Corti Distinguish Pitch?" the following conclusions are drawn:

(1) That neuro-anatomic and physiologic evidence is in favor of the resonance theory.

(2) Pitch perception is definitely placed on the basilar membrane of the cochlea.

(3) There is apparently a difference in sensitivity between internal and external hair cells. The external are responsible for the detection of very faint sounds. The internal hair cells are concerned with the fine discrimination of pitch.

(4) The external hair cells are more liable to degeneration than the internal hair cells.

(5) The chief cause of perception deafness is probably a degeneration of the external hair cells.

SECTION VII

VESTIBULAR NYSTAGMUS

44. General.—*a. Definition.*—Vestibular nystagmus may be defined as a rhythmic to-and-fro motion of the eyes, consisting of two components, a slow movement in one direction, which is followed at once by a rapid movement in the opposite direction. The slow movement is the vestibular reflex, yet the reaction has been named according to the direction of the rapid component. It has been shown that nystagmus always occurs in the plane of that semicircular canal in which the impulse calling forth the nystagmus arises and further that the slow component always takes the same direction as the endolymph movement, or that the rapid component takes a direction opposite to that of the endolymph movement.

The differentiation of the vestibular from the cerebral component of vestibular nystagmus has been demonstrated in certain cases in which the caloric experiment has been employed on patients under narcosis. In these cases the eyes remain fixed in the direction of the slow component until either the patient recovers from the anaesthesia or the muscles of the eyes tire, then the eyes assume their normal position.

b. Planes.—There are three main planes of vestibular nystagmus: Horizontal, frontal, and sagittal.

(1) Nystagmus in a horizontal plane consists of a movement of the eyes toward the right or toward the left.

(2) Nystagmus in a frontal plane consists of a rotary movement of the eyes on their antero-posterior axes, either toward the right or toward the left.

(3) Nystagmus in a sagittal plane consists of a vertical movement of the eyes either upward or downward.

The eyes are always drawn in a direction of the endolymph movement, this being the vestibular component, while the so-called direction of nystagmus, being that movement of restitution, is opposite to that of the endolymph movement.

c. Cause.—Nystagmus in the horizontal plane is due to stimulation of the horizontal canals and is quite simple, the fibers from the horizontal canals being distributed exclusively to the internal and external recti muscles. It has been demonstrated that the flow of endolymph toward the ampulla in the horizontal canal induces a stimulus twice as strong as when the endolymph flow is away from the ampulla. In turning, therefore, to the right the after nystagmus is to the left and is due two-thirds to endolymph movement toward the ampulla in the left canal, and one-third to an endolymph movement away from the ampulla in the right canal. In turning to the left the conditions are reversed. In turning, the endolymph at first lags, then catches up about the seventh turn and the movement continues in the direction of rotation for about 26 seconds after rotation has ceased. A great shortening in the after-nystagmus in one direction as compared with that in the opposite points to a nonfunctioning labyrinth on the side toward which the shortening is directed, for example, turning 10 times to the left equals a nystagmus to the right of 30 seconds; 10 times to the right equals a nystagmus of 15 seconds to the left. This would indicate that the left vestibule is either destroyed or its function abolished.

As previously stated the anterior or ampullar end of the horizontal canal is nearest to the tympanic cavity and is therefore most influenced by changes in temperature. With head inclined 60° backward the horizontal canals assume the vertical position. Douching the ear with cold water induces endolymph flow away from the ampulla. This causes a vestibular pull of the eyes toward the same side in the horizontal plane, hence a nystagmus in the horizontal plane to the opposite side. Hot water induces in the same position, endolymph flow toward the ampulla, and a vestibular pull toward the opposite side, hence a nystagmus in the horizontal plane to the same side as the ear douched. Similarly if the head is inclined 120° forward and the ear is douched with cold water the endolymph current is toward the ampulla, giving a vestibular pull of the eyes toward the opposite side, and a nystagmus toward the same side.

Nystagmus produced by the vertical canals is more complicated. The nystagmus produced is explained as follows: The anterior vertical canal lies in a plane halfway between the frontal and the sagittal and viewed from the outside of the head it runs from a forward position backward. The posterior vertical likewise lies in a plane halfway between the frontal and the sagittal, only it runs forward. The anterior canal is not placed in the frontal plane, nor is the posterior placed in the sagittal plane; the essential feature is

that the two vertical canals act together. This has been shown experimentally, either by douching with the head upright or turning with the head forward or backward. The plane of the resulting vertigo is the resultant of the planes of the vertical canals. Anatomically, at their innermost point, they unite in a common crus.

With the head 120° forward, on turning, the plane of movement of the head is frontal, and in this the frontal plane bisects the planes of the two vertical canals, causing a rotary nystagmus in the frontal plane. With the head inclined 90° toward the shoulder and turning in that position the plane of turning is sagittal and the resulting nystagmus is a nystagmus in the sagittal plane, that is, a vertical nystagmus upward or downward.

Turning to the right with the head 60° backward produces a rotary nystagmus to the left. Turning to the right with the head 90° forward produces a rotary nystagmus to the left. Turning to the right with the head inclined toward the right shoulder produces a vertical nystagmus downward. Turning to the right with the head inclined toward the left shoulder produces a vertical nystagmus upward. The exact opposite direction of nystagmus is produced if the turning is to the left with the position of the head as here indicated.

To stimulate the vertical canals for the production of nystagmus it is necessary to recall that the outer or anterior third and ampulla of the anterior vertical canal is nearest to the tympanic cavity and hence most influenced by temperature changes in the ear. Also that a current away from the ampullae here is twice as strong as a current toward the ampullae, the exact opposite to the horizontal canal.

With the head in the upright position, douching influences both vertical canals causing a nystagmus in the frontal plane. Cold water causes a flow of endolymph downward toward the ampullae, causing a vestibular pull of the upper meridian of the eyes toward the same side; in other words, a nystagmus toward the opposite side. Hot water gives the opposite effect.

The directions for carrying out the turning and douching experiments are given in section IX.

45. Differentiation between ocular, vestibular, and physiological nystagmus.—*a. Ocular.*—If the oscillations of the eyeball are a simple to-and-fro roll, like the swing of a pendulum, then it is not of the vestibular type but may be due to cerebellar lesions, certain ocular diseases, hereditary syphilis, neurasthenia, etc. Ocular nystagmus may be due to opacities in the media, etc., the patient attempting to look around the opacity as it were. Another cause of ocular nystagmus may result from an interference with the proper

action of light rays on the macula, provided that the lesion occurred before central fixation was established.

b. Vestibular.—The nystagmus due to vestibular stimulation or irritation exhibits a definite rhythm, a slow movement in one direction followed by a quick recoil in the opposite direction, and is due to a disturbance in the ocular nerve mechanism and not to a lesion in the eyes themselves. It can be produced by a lesion affecting any of the pathways between the ear and the eye muscle nuclei. Such a nystagmus is not due to an attempt to accomplish fixation. When the eyes are thus drawn to one side, impulses from the cerebrum to the eye muscle nuclei quickly bring the eyes back in the opposite direction. The slow component is caused by an irritation, impairment, or destruction of the pathways from the ear to the eye muscle nuclei, whereas the quick component results from the attempt of the cerebrum to correct the altered position of the eyes.

Vestibular nystagmus has the following characteristics:

(1) A quick movement in one direction and a slow movement in the opposite direction.

(2) It is increased, usually in rapidity and always in the length of excursion, when the eyes are turned voluntarily in the direction of the quick movement.

(3) It becomes weak, or may disappear wholly, when the eyes are turned in the direction of the slow movement.

This applies to vestibular nystagmus whether produced by experimental irritation or in the course of acute labyrinthine disease. Since irritation of a single canal can produce nystagmus only in its own plane, and since the nystagmus accompaning acute labyrinthine disease rarely corresponds exactly to the plane of any single canal, we may assume that suppurative invasion of the labyrinth almost invariably involves all, and always more than one of the three canals.

Rotary nystagmus can be followed with ease if we fix our attention upon some dilated vessel near the cornea and note carefully its changing relation to the border of the lower lid.

c. Physiological.—The term physiological nystagmus has been applied to the nystagmus which is seen in many normal persons when the eyes are voluntarily placed in the extreme lateral position in either direction. It is differentiated from nystagmus due to labyrinthine disease or irritation by the following points:

(1) Spontaneous vestibular nystagmus in its most active stage is constant, but is exaggerated when the eyes are voluntarily directed in the direction of the quick movement. Physiological nystagmus is

present only when the eyes are turned strongly in one or the other lateral directions, and then usually lasts but a few seconds.

(2) Vestibular nystagmus in its active stage is present whatever the position of the eyes. Later, however, as the strength of the nystagmus is gradually reduced, it may be wholly absent when the eyes are turned in the direction of the slow movement. Physiological nystagmus changes direction according to the position of the eyes, the quick movement corresponding to the lateral direction in which the eyes are voluntarily turned.

(3) Vestibular nystagmus in its most active stage is almost invariably accompanied by vertigo and ataxia and these symptoms, even after the nystagmic movements have grown weaker, can usually be reinduced by sudden movements of the head. Physiological nystagmus is unaccompanied by any subjective symptoms.

Section VIII

VESTIBULAR VERTIGO

46. General.—*a. Definition.*—Vertigo from whatever cause is a subjective sensation of a disturbed relationship to objects in space. As with nystagmus, so may vertigo and ataxia result from many functional and organic disorders.

b. Planes.—Vestibular vertigo is always rotary in character, that is, is always accompanied by a subjective impression of the rotation of surrounding objects, and this subjective rotation is always in a plane corresponding to the plane of the nystagmus. As there are three planes of nystagmus, so there are three planes of vertigo.

(1) *Sensation of turning in the horizontal plane, either from right to left or from left to right.*—Sensation of turning in the horizontal plane originates in the horizontal canals by rotation of the patient with head upright or inclined forward 30°. It is not unpleasant.

(2) *Sensation of turning in the frontal plane, consisting of falling to the right or the left.*—Turning in the frontal plane originates in

the vertical canals by rotation of the patient with the head forward or backward, and with the head in this position the plane of rotation is parallel to the floor and is not unpleasant, the sensation being the same as turning a patient with the head upright, namely, a movement about one's own axis either to the right or left. As it is a sensation of turning parallel to the plane of the floor it is not unpleasant; if, however, the patient's head is raised the frontal plane then becomes at right angles to the plane of the floor and the sensation is that of falling in the frontal plane either to the right or to the left.

(3) *Sensation of turning in the sagittal plane, consisting of a falling forward or backward.*—The sensation of turning in the sagittal plane originates when the vertical canals are stimulated in the sagittal plane, that is, with the head well inclined toward the shoulder while rotating. Here again with the head kept in this position the sense of rotation is parallel to the plane of the floor consisting of a sense of movement about one's own axis and is not unpleasant. If, however, the head is raised to the upright position, the plane of rotation is at right angles to the plane of the floor, and is decidedly unpleasant and causes a falling in the sagittal plane, either forward or backward.

c. Sensation.—(1) The essential feature of the subjective sensation of vertigo after turning is that after turning to the right the individual feels he is turning to the left, regardless of the position of the head. Vertigo being a cerebral phenomenon, in determining the interpretation of the sensation of movement, the cerebrum takes into consideration the head and in this way properly interprets the significance of the endolymph movement with the head in any given position. In the discussion on nystagmus it is found that since it is a simple reflex depending directly on the direction of the endolymph movement, the direction of nystagmus is influenced by the position of the head.

(2) As vertigo is always in the direction opposite to the endolymph movement the following subjective sensations of vertigo are produced by turning:

(*a*) *Turning to right.*

1. Head upright.—Sensation of turning to left.

2. Head 120° forward.

(a) Sensation of turning to left in horizontal plane.

(b) With head brought upright, sensation of falling to left in frontal plane.

3. Head back 60°.

(a) Sensation of turning to left in horizontal plane.

(b) With head brought upright, sensation of falling to right in frontal plane.

(*b*) Turning to the left gives exactly the opposite sensation of vertigo and falling.

47. Vertigo after douching.—*a. Water at 68°.*—(1) Douching right ear, head upright, produces sensation of falling to left in frontal plane.

(2) Douching left ear, head upright, produces sensation of falling to right in frontal plane.

(3) Douching right ear, head back, 60°, produces sensation of falling to the left.

(4) Douching left ear, head 60° back, produces sensation of falling to the right.

(5) Douching right ear, head 120° forward, produces sensation of falling to the right.

(6) Douching left ear, head 120° forward, produces sensation of falling to the left.

b. Hot water gives the opposite results.

48. Seasickness.—In speaking of the unpleasantness resulting from endolymph movements in the vertical plane, seasickness may be referred to as an illustration. A ship at sea tosses in various planes; stimulation of the horizontal or vertical canals results, depending on the position of the body in relation to the plane of the ship.

a. Horizontal plane.—From right to left. This is, however, very slight and is the only plane of movement that is not unpleasant.

b. Frontal plane.—A rolling from side to side. Facing the bow of the ship, the vertical canals are affected in the frontal plane, and this is unpleasant. By lying down with head or feet toward the bow, the rolling movement then affects the horizontal canals and the unpleasantness disappears.

c. Sagittal plane.—A pitching of the ship fore and aft. By standing and facing the bow, the vertical canals are affected in the sagittal plane, which is unpleasant. Lying down with the body extending across the ship from starboard to port, the pitching movement then affects the horizontal canals and the unpleasantness disappears.

d. The up and down movement of the ship, rising and sinking, in a similar way affects the vertical canals with the individual in the upright position. This unpleasantness is also relieved when the individual lies down, as then the up and down movement affects the horizontal canals, the stimulation of which is so much less unpleasant.

49. Past-pointing.—*a. Orientation and equilibration.*—It is necessary here first to consider the functions of orientation and equilib-

ration. By orientation is meant the determining of the relation of the body in space. Equilibration means the maintenance of position whether walking, standing, or sitting. Pointing may be considered a cerebral act of orientation. Past-pointing after turning or douching is not due to the misplaced position of the eyes or to the disturbance of vision, but is due to the stimulation of the ears. The normal person is always aware of the location of his hand or finger in space. Furthermore, with his eyes closed he is aware of the exact position in space of objects previously located.

b. Examinations.—The various examinations can be carried out with the shoulders either from above or from below; shoulder from the side and shoulder to the side, elbow from above and elbow from below; wrist from below; hip from below; neck from below; trunk from below. In this study of past-pointing will be considered only shoulder from above and shoulder from below, the patient in the latter touching the examiner's finger above, behind the subject's head, and to the side of the patient's head. In all of these methods of examination, the normal patient can with great accuracy and with eyes closed touch the finger of the examiner. After ear stimulation, however, with the production of a systematized vertigo, he is no longer able to touch the examiner's finger but past-points. If he feels he is turning to the left, he will past-point to the right; if he feels he is turning to the right he will past-point to the left.

c. Planes.—The plane of past-pointing is always in the plane of the vertigo producing it; the direction of the past-pointing is naturally opposite to the direction of the vertigo producing it. Here again are the same three planes. After an individual is turned with the head upright the horizontal canals produce a sensation of turning in the horizontal plane. Past-pointing, therefore, occurs in the horizontal plane to the right or left in the direction opposite to the subjective sensation of turning.

d. Sensations.—Turning sensations following rotation with the head inclined 120° forward are in the frontal plane and with the head in this position the frontal plane is parallel to the plane of the floor; in other words, the same as turning with the head upright. If the patient has been turned to the right he feels that he is turning to the left and past-points to the right. Now if after turning the head is raised, the frontal plane then assumes a position at a right angle with the floor giving a sensation of falling to the left in the frontal plane. As he feels that he is falling to the left he past-points to the right. Note that the result is the same after turning with the head forward; he will

past-point to the right whether the head is kept in the forward position or brought upright after turning.

Turning the individual with head 60° backward, the turning sensation is also in the frontal plane and with head kept in this position, the frontal plane is parallel to the plane of the floor, hence the sensation is the same as turning with the head upright. If he has been turned to the right he feels, therefore, that he is going to the left and past-points to the right. If the head is now brought to the upright, the frontal plane assumes a position at right angles to the floor. Immediately the previous sensation of turning to the left is changed to a sensation of falling to the right and he past-points to the left. This gives a complete reversal of the past-pointing and yet the explanation is simple and according to rule, that is, the past-pointing is in the direction opposite to the vertigo. We always consider vertigo in terms of our relation to what is in front of us or below us. After the turning to the right with the head back, the endolymph movement is to the right in relation to objects in front of us. When, however, the head is brought upright, this same endolymph movement is to the left in relation to objects above him. His sensation of vertigo is therefore immediately reversed when the head is brought upright.

With the head inclined toward the shoulder, turning produces the subjective sensation of turning in the sagittal plane of the head and as this plane is parallel in this position with the plane of the floor, the individual past-points in a horizontal plane either right or left. If the head is now brought upright, the plane of subjective vertigo becomes a right angle to the floor, producing a sensation of falling in the sagittal plane forward or backward and a past-pointing in the sagittal plane either above or below. Turning to the right with the head inclined toward the right shoulder, and then bringing head upright produces past-pointing upward. Turning to the left with the head inclined toward the right shoulder produces past-pointing downward when the head is brought in the upright position.

50. Past-pointing after douching.—*a. Water at 68°.*—(1) Douching right ear with head upright produces past-pointing to right.

(2) Douching left ear with head upright produces past-pointing to left.

(3) Douching right ear, head back 60°, produces past-pointing to right.

(4) Douching left ear, head back 60°, produces past-pointing to left.

(5) Douching right ear, head forward 120°, produces past-pointing to left.

(6) Douching left ear, head forward 120°, produces past-pointing to right.

b. Hot water gives diametrically opposite reactions.

51. Past-pointing cerebral function.—*a.* Past-pointing is not an ear reaction. Ear stimulation produces only two reactions, nystagmus and vertigo. Ear stimulation causes a pulling of the eyes, this being a simple reflex as explained. Vertigo is not a reflex, but is a subjective disturbance of the cerebral cortex due to sensory impulses received directly from the ear. Pointing, on the other hand, is a cerebral act. Neither turning nor douching causes one to past-point. The subject is asked to raise his arm and then bring it back to find the finger. Before ear stimulation he can do so; after stimulation he is unable to find the finger because of the vertigo. Therefore, the law of ear tests: where there is no vertigo there is no past-pointing. Vertigo is the primary reaction; past-pointing the secondary manifestation. One conception of past-pointing is that it is due to a cerebellar pull of the arm to one side, in the same way that the eyes are drawn to one side by the stimulus from the labyrinth. Past-pointing, however, is not a cerebellar function; it is cerebral. Spontaneously, the cerebral mandate is to find the finger at the exact point where it is; after ear stimulation the cerebral mandate is to find the finger where the cerebrum now conceives it to be. In either case the cerebellum carries out the cerebral command with accuracy.

b. Proofs of the above are supplied by the following:

(1) Successive greater past-pointing if the examiner catches the finger each time after a given rotation or douche.

(2) Compensation, that is, if an intelligent subject knows that he usually past-points say 12 inches in a given direction, he can deliberately over-correct or correct.

(3) Duration of vertigo and duration of past-pointing are equal.

(4) Moving finger up and down after turning is accomplished in a vertical plane, deviation or past-pointing only occurring if he touches some external object and then tries to touch same again. Here the sensation is one of leaving the object touched behind him and thus past-pointing to touch same.

(5) The results of turning with the head back 60° being the same as rotating with the head forward 120° in the same direction. This has been previously stated and need not be repeated here.

c. The tracts for pointing and for past-pointing are one and the same. The paths of the sensory impulses from the ear to the cerebral cortex producing vertigo have been explained. The pointing paths are purely motor. They begin in the motor area of the cerebral

cortex and end in the peripheral distribution to those particular muscles which are employed in the pointing tests. These paths are two:

(1) *Pyramidal tract.*—The power tract, which supplies the motor force for pointing.

(2) *Cerebro-spinal tract.*—The accuracy tract.

Through this tract the cerebellum is able to exercise its synergic or inhibitory influence. The pyramidal tract alone would be able to supply the necessary energy for the movement, but it is the cerebellum that enables the arm to point accurately. Jones explains this accomplishment as follows: In the cerebellar cortex are separate centers, one for the outward pointing and one for the inward pointing of different joints. As the arm descends to find the finger, if it tends to point outward, the inward pointing center restrains this aberrant movement and draws it back to its proper course and vice versa.

52. Falling.—Falling after ear stimulation may be considered as a past-pointing of the whole body. The patient falls because of the vertigo. Falling is not in evidence when the subjective sensation of rotation is in the horizontal plane; in this the individual feels that he is being rotated on his own vertical axis and there is no tendency to fall. If the vertigo is in a frontal or sagittal plane he tends to fall either to one side or the other, or forward or backward. Under all circumstances both the past-pointing and the falling are always in the direction of the endolymph movements.

Vertigo being always in the direction opposite the endolymph movement, falling and past-pointing, being dependent on the vertigo, are in a direction directly opposite to the subjective sensation of movement. Falling reactions, as the past-pointing, are cerebral. The patient, having a sensation of falling to the right, throws his body to the left and falls to the left, and vice versa.

After turning to the right with head forward the patient raises his head and falls directly to the right. With the head in the upright position the endolymph movement is to the right, and therefore falling is in the frontal plane to the right, the vertical canals having been stimulated in the frontal plane in the turning with the head forward.

Falling in the sagittal plane is produced when the vertical canals are stimulated in the sagittal plane, as with the head inclined toward either shoulder.

53. Falling after turning.—*a. Rotating to right.*—(1) Turning to right, head 120°, and sitting upright, produces falling to right.

(2) Turning to right, head back 60°, and sitting upright, produces falling to left.

(3) Turning to right, head inclined toward right shoulder, and then bringing head to upright position, produces falling backward.

(4) Turning to right, head inclined toward left shoulder, and then bringing head upright produces falling forward.

b. Exactly the opposite results are obtained by rotating to the left.

54. Falling after douching.—*a. Water at 68°.*—(1) Douching right ear, head upright, produces falling to right.

(2) Douching right ear, head back 60°, produces falling to left.

(3) Douching left ear, head upright, produces falling to left.

(4) Douching left ear, head back 60°, produces falling to right.

b. Hot water gives directly opposite results.

55. Summary.—The entire physiology of the ear tests may be summed up in four sentences, as follows:

a. The eyes are always drawn in the direction of the endolymph movement.

b. The vertigo is always in the direction opposite to the endolymph movement.

(1) Past-pointing is always in a direction opposite to the vertigo.

(2) Falling is always in a direction opposite to the vertigo.

Section IX

VESTIBULAR TESTS

56. General.—*a. To whom given.*—For many years the vestibular tests were required on all original examinations. This was a hold-over from the early days of aviation when undue stress was placed upon the labyrinth. It was believed that to be a good pilot one must possess an unusually refined type of labyrinth in order to imitate the birds. With increased experience the "sense of equilibrium" has now been given its proper evaluation in the examination and vestibular tests are given in the following types of cases:

(1) Those who give a history of trainsickness, seasickness, swing-sickness, or airsickness.

(2) Unsteadiness on the self-balancing test.

(3) Cases showing marked tremor of lids and fingers.

(4) Unsteadiness on Romberg and gait tests.

(5) Cases who have a sitting pulse of over 90.

b. Equipment.—All tests are given in a turning chair equipped with an adjustable headrest, a foot support, and a stop pedal.

c. Reactions tested.

(1) Nystagmus, to the right and left.

(2) Pointing (past-pointing), to the right and left.

(3) Falling, to the right and left.

d. Technique.—The technique for making the above tests is given in the following paragraphs.

57. Nystagmus.—With head 30° forward, so that the tragus of the ear is on a horizontal line with the external canthus of the eye, the examinee is asked to fix his eyes on a distant point and the chair is turned slowly from side to side in order to note whether or not a spontaneous nystagmus is present. Then turn examinee to the right, eyes closed, ten times in exactly 20 seconds. The instant the chair is stopped click the watch; examinee opens his eyes and looks straight ahead at some distant point. There should occur a horizontal nystagmus to the left of 26 seconds' duration. Examinee then closes his eyes and is turned to the left; there should occur a horizontal nystagmus to the right of 26 seconds' duration.

For all three classes a nystagmus of 10 to 34 seconds is qualifying, provided it is approximately of the same duration in the two directions. Any variation in the two directions of more than 5 seconds should arouse suspicion of labyrinthine or brain disturbances and should call for the caloric douche test.

58. Pointing.—*a.* Examinee closes eyes, sitting in chair facing examiner; touches the examiner's finger held in front of him; raises his arm to perpendicular position; lowers the arm and attempts to find the examiner's finger. First the right arm, then the left arm. The normal is always able to find the finger.

b. The pointing test is again repeated after turning to the right ten times in 10 seconds. During the last turn the stop pedal is released, and as the chair comes into position it becomes locked, care being taken to ease the chair into the slot so as not to throw the examinee out. The right arm is tested; then the left; then the right; then the left, until he ceases to past-point. The alternating of arms is kept up even after he ceases to past-point with one arm. The examinee should watch the arm at the top of the swing. Experienced flyers often correct their past-pointing before the arm is brought down. If there is no past-pointing at the bottom of the swing, have the candidate past-point from below up. The normal will past-point to the right three times with each arm. If he past-points once in each direction with each arm, the test is satisfactory for all classes of examination. If

he past-points more than six times, he will be disqualified. This applies to all three classes of examination.

c. Repeat pointing test after turning to the left.

59. Falling.—Examinee inclines head 90° forward, resting his forehead on his upper fist, his fists being placed one above the other on his knees, which are brought close together, or the headrest may be used. Turn to the right five times in 10 seconds. On stopping, examinee raises his head and should fall to the right. This tests the vertical semicircular canals. Turn to the left, head forward 90°; on stopping, the examinee raises his head and should fall to the left. The examiner should place his hand in readiness to press on the back of the neck of the examinee as he starts to sit up. When it is clear that he is falling properly, force his head down again, as this will avoid many of the disagreeable sensations. If this test is unsatisfactory, give him the caloric douche test. Unless each test is normal, it is a cause for rejection for any class.

60. Caloric douche test.—So-called borderline cases can be tested by the caloric test, each ear separately. Water at 68° F. is allowed to run into the external auditory canal from a height of about 3 feet through a stop nozzle with the head tilted 30° forward, until the eyes are seen to jerk and the individual becomes dizzy. This should be accurately measured by a stop watch. The type of nystagmus is then noted. With head in upright position it should be rotary and the direction of the jerk should be to the side opposite the ear douched. The length of the douching shown by the stop watch in the normal is 40 seconds. The eyes are then closed and the past-pointing is taken. The head is then immediately inclined backward 60° from the perpendicular; there should appear a horizontal nystagmus to the side opposite the ear douched. The eyes are then closed, and the past-pointing is taken with the head in this position. The left ear is then douched, and the same procedure is carried out. If instead of 40 seconds of douching there was required not more than 90 seconds, the examinee is not rejected. Care should be taken that the cold water reaches the drumhead, as wax or other obstruction in the external canal would interfere with the responses in a perfectly normal individual.

SECTION X

BLIND FLYING

61. General.—*a. Essentials.*—To master blind flying the pilot needs just two things—a knowledge of his instruments and a knowl-

edge of his ears. Unless he understands the sensations from his ears, he is at least bound to pass through a disturbing period, which is entirely unnecessary. More than this, his lack of knowledge about his ears may lead to disaster.

b. Popular conception.—In the popular mind blind flying has an element of mystery. Not so long ago certain of the transport companies in their publicity gave the impression that "their pilots were able to fly in any kind of weather." This sort of thing only adds to the impression that there is only some particular and remarkable type of pilot that is able to do this mysterious thing, and that if one

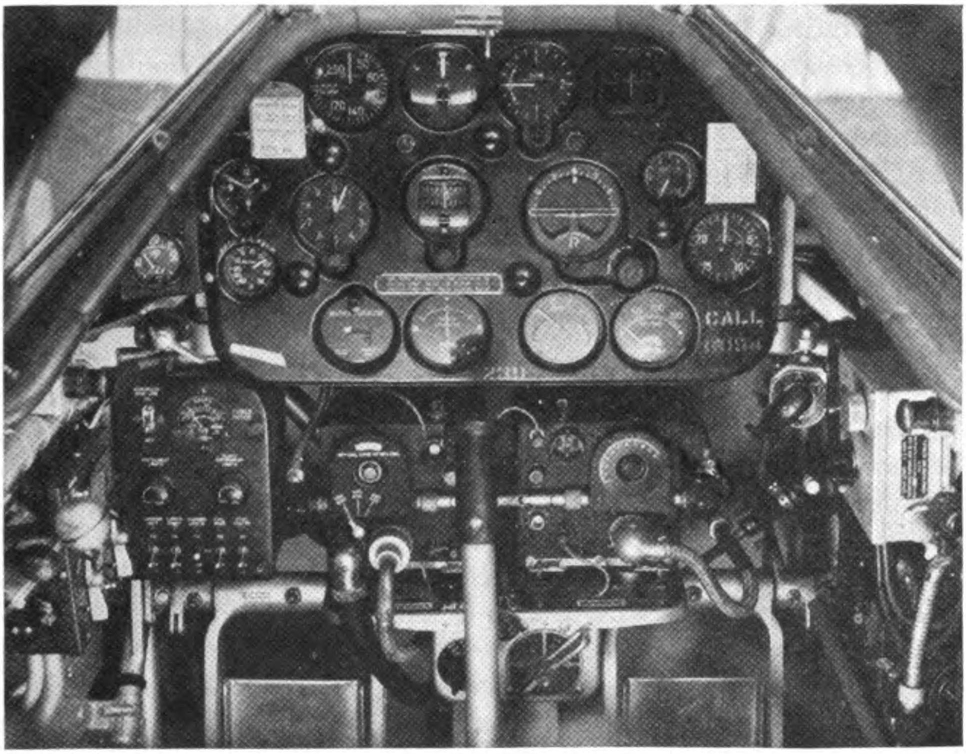


FIGURE 2.—Instrument board equipped for blind flying.

flies in bad weather and arrives safely, he ought to congratulate himself and feel that he is very fortunate to get through. So far as the special senses of the pilot himself are concerned the human side of this problem was thoroughly understood in 1918.* Today if there is anything in the world mastered, known thoroughly, it is the principles of blind flying.

c. Improvement.—"Blind flying" is also termed "instrument flying." There will be improvements in the instruments of precision, and every

*Isaac H. Jones, M. D., *Equilibrium and Vertigo*, J. B. Lippincott Company, 1918.

little improvement will, of course, be welcomed. But one should know that the present instruments are first-rate. They work. One should think not only of the future, but should realize what is being done right now.

d. Blind landing.—"Blind landing" is the next step. The first blind landing was made in 1928. Soon after this a blind landing was done in a covered cockpit. The pilot could see nothing except his instruments. He flew west for 15 miles, then back until the "radio beam" told him he was directly over the landing field, then east for 2 miles, turned and headed back for a beautiful three-point landing; then he got out and took a look around for the first time since he had started on the flight. In the past 2 years so much has been done in blind landings that soon this also will become commonplace. It will then be taken for granted, just as today blind flying is taken for granted.

e. Safety.—It used to be very dangerous to fly "blind." But it need not be so today. With the necessary instruments, any good pilot who understands his own ears and is taught to fly blind can now do so with complete safety.

f. Ear—instrument discrepancy.—All that is known today about the ears and how they work was known back in the beginning, but the instruments were not available. These precision instruments are accurate and dependable. They give the pilot definite information, but his ears may give him contradictory information when he is flying blind. The instruments tell him one thing, but he feels another thing. Therefore, the pilot's difficulty today lies in his attempt to reconcile what the instruments tell him with what he feels. It is a very simple problem with a simple answer. Any pilot can understand the essentials of his vestibular sense after ½ hour's instruction by a flight surgeon. Every pilot, either military or commercial, should be required to receive this instruction. It is so simple, but so important. The earlier the pilot receives this instruction, the better. The ideal would be for every student pilot to be taught to fly blind as soon as he has learned the mere rudiments of flying. The beginner has no difficulty in learning blind flying; the veteran pilot has great difficulty. He has to unlearn so much. Such instruction in the vestibular sense by a flight surgeon is the very basis for training in flying blind.

g. Origin of studies.—Studies of blind flying were begun in May 1917 by a pilot and a flight surgeon. At the beginning of the World War, at Essington, Pennsylvania, there were two little 1915 Curtiss Pusher seaplanes and 20 cadets. There was a similar little organiza-

tion at Mineola, Long Island, and another at North Island, San Diego. That was about all there was to the air service at that time. The investigators could only speculate about the problem. It was known that flying, more than any other activity, would make the most exacting demands upon the eyes, the nervous system, and the heart. But even in the beginning it was sensed that the brand new problems in aviation were those of the vestibular sense (whirling, airsickness, and blind flying) and the problems of oxygen want.

h. Ear problem.—Considerable was already known about the oxygen problem. For many years this had been studied, on high mountains and in balloon ascensions. But in the problem of whirling and blind flying there was nothing whatever to guide. No one knew anything about rotating in the air and its results. It was known that it is an ear problem; that the ears of the aviator should not be "dead" or too active; and it was realized that the vestibular sense had a greater importance in aviation than in any other human activity. But it was not known until later how vital it is for the aviator himself to understand these little organs which even to this day so few pilots realize are hidden away in their skulls.

i. Weather.—At that time nobody actually went into a cloud if he could possibly avoid it. In fact, he always waited until the wind died down before going up, usually about 5 P. M. or about sunup. Pusher airplanes were barely able to maintain flying speed. They were unsafe except under the best weather conditions—and not safe even then. It never occurred to anyone to fly in bad weather. So at first there was no chance to study the problem of flying blind. At that time all that was known was that an earnest study of the "ear and aviation" must be made.

j. Ear senses change in motion.—Before there was actual experience, it was wondered whether the ear might enable the pilot in a fog to tell whether he was right side up or upside down. This was a forlorn hope. It was soon found out that neither the ear nor any other organ can keep one straight when he is flying blind. The ear cannot tell position in space. When a plane takes off, the ear senses the sudden change of speed; when it is flying at a constant speed the ear senses nothing; each change of speed gives a new sensation; but in a well executed banked turn the ear is not affected in the least, since the pull of centrifugal force neutralizes the pull of gravity. The ear is not affected because it senses only a change of motion. So the senses cannot tell one where he is.

k. Importance of ear studies.—For a while too many came to think that if the ear could not do everything as hoped, there was no need

to pay much attention to the ear or to ear studies. The ear went under a cloud of disapproval. But as time went on it was found out that a good foundation had been laid in creating studies of the ear, which organ it is far more important for the pilot to understand than was dreamed back in the beginning.

l. Information from ear.—Like the eye, the ear can give correct information and it can also give incorrect information—illusions. What correct information the ear gives to the pilot should be considered before illusions.

m. Source of sense of motion.—How is motion sensed, anyhow? Where does the information come from so that one is able to detect whether moving or not? One cannot tell much by the senses of touch, smell, or taste. Practically all information comes from three sources—the eye, the ear, and the "general" sense. It is known that the eye and the ear can detect motion, but what is meant by the general sense? The brain receives information from the muscles, joints, the intestines—and in fact from all parts of the body. This is what is meant by the general sense. From different parts of the body nerves go into the spinal cord, which carries the impulses to the brain. If one has, for example, locomotor ataxia, these impulses are interrupted. Such a person has a poor general sense.

n. Motion in vertical line.—Experiments were performed during the World War to find out what information the pilot gets from the eye, the ear, and the general sense. The detection of motion in a vertical line was studied in elevators that made a trip of 40 stories, a height of 400 feet. The elevator shafts and the men were in the dark so that no information could come from the eyes. The elevator car was lined with thick blankets so that no information could come from the sense of touch. The individual could learn nothing except for his general sense and from his ears. Three groups of men were selected—normals, deaf-mutes with no vestibular function, and patients with locomotor ataxia who lacked the normal general sense. These studies showed that the general sense could inform the individual when his movement was changing. The direction of the motion was chiefly determined by the ear. The ear was not accurate in telling that the elevator had stopped because the wave impulses in the ear still affected the ear, even though there was no motion. This is the illusion. It is the same thing that happens after turning to the right in the turning-chair and stopping—one feels he is turning to the left, although he is actually sitting still.

o. Feel of ship.—The next study, on the "feel of the ship," was made in actual flight. The pilot sat in the rear cockpit and the one to be

tested in the front cockpit. When about to change from the straight line, the pilot would reach forward and tap the man on the shoulder. The man would then write down what he thought the airplane had done. Those with normal ears were compared with seven deaf-mutes that had no vestibular function. All were blindfolded. Those with normal ears were fairly accurate in their detection of motion during these flights. The deaf-mutes were not.

p. Air—chair relationship.—As a result of these studies it was concluded that one who shows good responses in the turning-chair shows good detection of motion in the air. One who shows poor responses in the turning-chair shows poor detection of motion in the air. It was expressed, "There is a direct relation between the chair and the air, and the air and the chair."

q. Contributions of psychologists and physiologists.—Earnest work was also conducted by a group of eminent psychologists and physiologists. Before, it was thought that the nystagmus could not be altered by experiences in turning; they showed that if a man is turned, over and over again day after day, the duration of the nystagmus would become shorter and shorter. Also, it had been thought that the fluid in the ears actually moved; their experiments suggested that it does not move. A scientific storm raged for years on this subject. Otologists said it did move and the psychologists said it didn't. Of course, so far as tests of the ears are concerned, it makes no difference whether there is an actual movement or a wave impulse. The latest work on this subject was done by injecting india ink, and then one drop of oil, into a semicircular canal of a fish. It was shown that, after turning, the drop of oil follows the movement of the fluid in the canal; that the eyes jerk only when the hairs are displaced; and that, although the movement acts for only a short time, the displaced hairs do not regain their normal position for 20 seconds. Regardless of different opinions it was known that either an actual movement or a wave impulse does occur and that this results in a displacement of the hairs.

r. Education of senses.—To this day most aviators still think it is a weakness if they have dizziness, nausea, or any other vestibular response, either in the turning-chair or in the air. There were also some doctors who thought that the safest aviators would be those whose ears do not work—because they do not have the illusion which normal persons have after spinning nose dives and other whirling maneuvers. This sounds plausible until a little thought is given to it. All normal sense organs can give illusions. Surely the aviator needs all the information that he can get from all of his senses. First of all he needs normal senses, including the vestibular sense. He then

needs the education of all of his senses, including the vestibular sense. In mastering seasickness, or whirling dances, or acrobatics, the brain must learn to interpret the unusual impulses from the ears. A whirling dance may be well performed by a beginner, but the expert dancer can suddenly stop still without falling. The beginner falls down simply because he has not had experience. The difference between the artist and the beginner is that the artist has come to understand the impulses from his ears.

s. Cat question.—After the World War, work was done to settle the problem of how much each of the senses contributes to the detection of motion. Although it was not recognized at the time, a way to do it was found. It seemed that one of the most remarkable feats is performed by the cat when he falls in the air. He always rights himself and always lands on his feet. The question was, "Why and how does a cat turn over?" It was felt that if this could be discovered, exactly how much each of the senses contributes to the detection of motion would be known.

t. Experiment.—Cats and dogs were dropped and their movements from the moment they were dropped until they landed on a soft mat were analyzed by means of slow-motion photography. The animals were held upside down and then dropped. First normal cats and dogs were studied; then a number of the cats were operated upon. Of course the operations were done under ether and the cats were nursed until they had fully recovered. Then the pictures were taken all over again.

u. Results.—By watching the slow-motion pictures every detail of the movements of the animals can be seen.

(1) *Normal cats, kittens, dogs, and puppies.*—Immediately after they are dropped, all cats and kittens turn right side up—extend all legs downward with back humped upward, float downward, and land perfectly. The dogs do the same, only the dogs do not turn so promptly and do not hump the back so much.

(2) *Same normal animals blindfolded.*—The cats and kittens turn over just as promptly as with the eyes open; hump the back just the same and land as well, but crawl away with bellies close to the mat.

(3) *Cats and kittens whose internal ears had both been operated on, and were not working—eyes open.*—Do not turn over. On descending, roll over and over until earth is struck.

(4) *Same cats and kittens blindfolded.*—Same result, except that on landing, crawl off with bellies close to the mat.

(5) *Cats and kittens with one internal ear not working.*—Better performance than those with both ears not working, but not so good as the normal.

(6) *Cat with one ear not working plus absent cerebellar hemisphere of opposite side.*—(The "cerebellum" is the "small brain"; it coordinates movements.) Indefinite but generally poor, both in delayed turnings and variable landings.

(7) *Cat with one ear not working plus absent cerebellar hemisphere of same side.*—Same result.

(8) *Cats with removal of one cerebellar hemisphere without operation on either ear.*—Turn over very well, both with eyes open and blindfolded. Performance almost as exact as that of normal cats.

v. Conclusion.—When these studies were started it was known that the ear played a part; when they were completed it was found that the ear is really the answer. When the cats were actually dropped very little could be told. It all went too fast. But the slow-motion pictures were so beautifully taken that each animal could be seen to turn over and then slowly drift to the mat. The normal animals, blindfolded, turn over just as promptly as when their eyes are open and then float downward until they make a perfect landing. But these same cats, after their ears are operated upon, do not turn over at all, even when their eyes are open. On descending they roll over and over and make no attempt to right themselves. So the importance of the ear in sensing motion was realized. The complete "feel of the ship," which is the "sense complex" that makes for a first-class pilot, requires internal ears that are working.

w. Vestibular sense.—From the pilot's standpoint it is all very interesting for him to know how important his ears are in his detection of motion. He realizes that he is constantly receiving important information from his ears (without being in the least conscious of it). But it is so much more important for him to understand his vestibular sense because of the illusions. These illusions have disturbed every man or woman who has ever gone up into the air. All pilots have come to disregard them so long as they can see. The serious thing is for the pilot not to understand these illusions when he can't see. But while one studies "how the ear can fool one" he must always keep in mind that it is the normal ear that is capable of giving the illusions. But the eye or ear is not merely an organ that may at times give illusions. They are both constantly giving good and helpful information, invaluable in seeing, in hearing, and in sensing motion.

x. Conception of airplane.—It was originally thought that the airplane was an automobile with wings, that this contrivance simply went up in the air instead of running along on the ground, and

that, relying upon senses, one could drive it just as he was accustomed to drive an automobile. The change in the attitude of flight surgeons as well as pilots during the succeeding months and years came with experience. They came to realize that the airplane is not an automobile, but a ship—a ship navigating the ocean of the air. One of the great reasons for advancement and safety in flying is this change in mental attitude toward it.

y. Birds and blind flying.—Any overconfident pilot who still feels that he can rely upon himself and his own senses in meeting all the conditions in the air is in danger. He is apt to come to grief. Through all the ages the bird has been meeting the conditions in the air. He has internal ears of tremendous size and he has used these and the parts of the brain that are connected with the ear through countless experiences from the time when the first bird took to the air. Yet a bird always avoids a fog or a cloud. A bird is not found flying in the clear air above the clouds—no doubt because he did not wish to fly up through them. In short, even the bird is not at his ease when he is flying blind.

z. History of precision instruments.—(1) The answer to the problem of blind flying is instruments of precision. Much time passed before instruments of precision were available for the airplane. Through all the early years most aviators felt that their natural instincts were better guides for operating their craft than the best instruments available. Years were required to convince the majority of fliers that their old belief was wrong and the cause of so many fatal crashes. Wilbur and Orville Wright were conspicuous exceptions. They designed the first instrument ever used. It was a string about 8 inches long. This cord was fastened in front of the pilot with one end swinging free. So long as this string pointed directly at the pilot's nose the ship was flying without slipping or skidding. This was in 1912. In 1914 they brought out a pendulum bank-indicator, and also an accurate rate-of-climb indicator. These two were used in conjunction with the earlier string. But they found it difficult to get even their own student pilots to use these instruments because of the humiliation when other aviators would say that the sudents of the Wright Brothers found it necessary to use instruments in flying. In other words, for many years instruments were not popular. Fliers took pride in scorning them.

(2) Until the World War began in 1914, airplanes carried few instruments. These as a rule were crude; and air activity ceased during foggy weather. The reverse will probably be true in future wars, and most of the flying will purposely be done in bad weather.

(3) Blind flying had its real beginning for our country in 1917 when a "turn indicator" was produced. That year, with the aid of this instrument, a fog flight over the Allegheny Mountains from Washington, D. C., to Ohio was made. This turn indicator was described by its inventors as a "crutch" for the magnetic compass.

(4) The modern instruments include the Sperry gyro-horizon, the directional gyro, the turn-and-bank indicator, the rate-of-climb, the rate-of-speed, the sensitive altimeter, and the flight integrator, now being perfected. It is the combined use of all these instruments that stabilizes the mind of the pilot. Each instrument makes its own contribution. The end result is that the pilot has a definite conception of his position in relation to the external world. In other words, all of the precision instruments combine to tell the pilot his position and his relation to the horizon.

(5) These instruments are so reliable that one would think it a simple matter for anyone to rely upon them and fly safely in any kind of weather. To this day, however, many a pilot is sending his instruments back to the manufacturer to have them corrected—only to have the instruments returned with the information that they are in perfect condition. In brief, such a pilot does not trust his instruments, because his own sensations conflict with what the instruments tell him. All his anxiety is unnecessary.

aa. Ear deaths.—If one analyzes the disasters of modern aviation, he cannot fail to be impressed with what has come to be an old story: "bad weather," "fog," "storm"—in brief, blind flying. During the World War each crash was investigated by a committee consisting of the commanding officer, the officer in charge of flying, and the flight surgeon. The results of all of these crash reports were studied and tabulated. Many of the accidents were caused by weakness of the airplane and motor failure. Certain airplanes burned in the air and in those days there were no parachutes. In addition many crashes were due to what was even then termed "ear deaths." There is a great contrast today. Structural defects and motor failures are practically unknown. The "ear deaths" still occur.

ab. Illusions.—(1) In the railroad station one is sitting at the window of the car looking out. Suddenly his train starts to go forward. He rushes out to the platform to wave good-bye to friends, but the friends are still there and so is the platform. He was not moving; it was another train that was coming toward him. Immediately he is at his ease. He thoroughly understands the situation. He knows where he is and why.

(2) Now consider the illusions that may come from the ears, particularly in blind flying. In a fog, after the pilot has rotated in the air and the ship straightens out, his own head is no longer actually turning. But anyone who knows the first thing about the ear knows why he feels that he is rotating in the opposite direction. In other words, in the railroad station one has an illusion from his eyes, and now one has an illusion from his ears. He feels that he is going in the opposite direction when he is not. He has "vertigo"—a sensation of movement contrary to fact. All he needs to do is to look at the instruments in front of him and believe in them. Immediately he disregards the feeling that he is turning. He pays no attention to his feelings. He understands them. The sensation in the head of the pilot is exactly the same as when one comes out of the railroad train and looks at the platform. The illusion is gone. He knows the facts of his position.

ac. Ruggles orientator.—In 1918 the Ruggles orientator was a great step in advance. It is, so to speak, a turning-chair that revolves in every direction. The pilot sits in a cockpit and rotates it in every possible direction. This was, and is, a great help, because it enables the pilot to get used to these queer sensations while he is safely on the ground.

ad. Training.—The pilot should be trained to understand his ears. First he taught with the "instrument box on the turning-chair." Then he is instructed in actual flight "under the hood." *

(1) *Instrument box on turning-chair.*—(*a*) The "instrument box on the turning-chair" is the key to blind flying. The principle is to show the pilot how to understand his ears and his instruments at the same time. The procedure is simple. The pilot is rotated—preferably in the presence of other pilots. He is turned to the right and then the chair is stopped. He calls out, "I am turning left, to the left." He is then turned very rapidly to the right, and then slowly to the right. He may say, "I am not moving," or "I am turning to the left," whereas all the observers assure him he is turning to the right.

(*b*) The pilot is then told to look into the instrument box. A flashlight in the box shows a turn-and-bank indicator and a compass. As he looks at the instruments he is again rotated. He watches the instruments while he is being rotated. He says, "I am turning right; the indicator also shows I am turning right." When the speed of the chair is slightly reduced, he will say, "The indicator shows I am turn-

Blind Flight, by Lt. Col. William C. Ocker and Capt. Carl J. Crane, published in 1932 by the Naylor Company, San Antonio, Texas.

ing right; my senses tell me that I have stopped," or "The indicator says that I am turning to the right, but I feel that I am turning to the left."

(*c*) It frequently happens that the pilot who has just had this demonstration will argue that his sensations are correct, in spite of what the instruments tell him. In that case it is helpful to have him stand by and watch someone else go through the same performance. As a rule a few such experiences in the turning-chair will convince the pilot that he can rely upon the instruments. His thought then is "Oh, yes, I have that feeling of turning, but I am not actually turning." From that moment his problem is solved.

(2) *Hood.*—(*a*) The next step is actual flight under the hood. Such instruction requires more time, largely because of the element of fear. But after the pilot has mastered flying under the hood he no longer has any fear or apprehension when he suddenly enters a cloud. The most difficult fliers to train are the old veterans. Blind flying should be taught early—the sooner the better. As soon as a pilot is at his ease in flying blind he has then mastered the situation. When he suddenly enters a cloud he feels at home. When he is able to see, so much the better.

(*b*) To teach the pilot to interpret his instruments and respond automatically to what the instruments tell him, a hood was put over the cockpit in the Ruggles orientator, which can be "flown" by either the pilot inside or his instructor outside. The orientator rotates the pilot in every conceivable manner; the more recent Link trainer has more limited movements, but it duplicates many of the motions of the airplane—the turns, banks, glides, and climbs. After he gets out of the orientator or the trainer, the pilot can see how well he responded to his instruments, because his performance is recorded on a chart. In addition to becoming familiar with the instruments the pilot is also receiving messages through his earphones and learns to interpret the direction signals by radio. This not only helps him to fly blind but instructs him in "avigation," which means the navigation of the air. When flying blind, the pilot must not only be able to keep the plane in proper position but must be able, by avigation, to arrive at his destination. This is best accomplished by radio messages which guide him to the proper place.

ae. Sperry gyro pilot.—There is one motion-sensing device that is perfect. It detects changes of motion accurately. It has absolutely no illusions. This device is the Sperry gyro pilot. It is now in use on most of the air lines everywhere. The attractive feature of the gyro pilot is that it is automatic. The human element is eliminated. The gyro pilot not only detects motion—it actually operates the

controls and holds the airplane in correct flying attitude. About 75 percent of all air-line flying in the United States is now done by the gyro pilot.

af. Ignorance of pilots concerning ear.—A thorough knowledge of the ear has been available to the pilot since 1918. Of course, fliers would not see, or understand, the medical books; but it is hard to understand why, in some way, they have not become acquainted with at least the simple facts that have been known for such a long time. To this day, out of one thousand pilots there is perhaps only one who knows that he has a vestibular part of the ear. Any intelligent pilot simply needs to be told the following: Remember that just because the eye can fool one, it does not mean that one does not need his eyes. And just because the ear can fool one, it does not mean that one does not need his ears. It is highly desirable to have good eyes; and in flying more than in any other occupation one will be helped by normal motion-sensing impulses from the ears. With all one's organs and senses, the nearer one is to a full normal the better it is for him. One must simply come to understand his ears, not only for the correct information which they give, but for the incorrect information which they may give, when flying blind. In clear weather the ear helps to give the "feel of the ship." In a fog, after one comes out of a spin and the ship straightens out, he feels that he is spinning in the opposite direction. If the pilot simply looks at his instruments and believes in them, he will know the facts of his position. He will realize that his sensations are contrary to fact. In brief, just as the eyes can fool one, so the ears can fool one. But the difficulty is that although one knows perfectly well what the eyes are for he does not understand his ears. The ear is thought of as the motion-sensing organ that receives impulses from without—what is called hearing. But it is the other part of the internal ear, the part that senses the motion of the airplane and the pilot, that is far more important to understand. Knowledge of this little organ may make all the difference between safety and disaster. A pilot will be much better and safer if he studies and understands this little motion-detector in his internal ear.

62. Medical contribution.—*a. Conception of term.*—Many aviators and most laymen have no proper conception of the term "blind flying." To the vast majority it simply means flying when the pilot cannot see things clearly. To the properly trained aviator, the ability to do blind flying, and to understand the basic underlying human reactions governing the same, means the difference between life and death.

b. Popular education.—The pioneer medical research work accomplished during 1926 firmly established the basic principles from the *human* standpoint on which the art of blind flying is founded. A report of this research and the conclusions arrived at were placed on file in the office, Chief of the Air Corps, War Department, in 1926. Following the filing of this report, articles began to appear in many popular and technical magazines, newspapers, etc., on "blind flying." These articles were prepared by "feature writers", usually after an interview, and were released for the purpose of bringing this new discovery in aviation to the attention of the public and to create an interest in the matter by aviators in general. Naturally, the dramatic side was emphasized. Many lectures and demonstrations before civic bodies, clubs, and technical societies were given. In all of the articles published and the lectures and demonstrations given, the basic principles discovered were freely discussed and explained, resulting in a more or less general understanding by the public of the underlying *physiological* reactions experienced in blind flying.

c. Definitions.—(1) *Blind flying.*—Research work attains value of importance only when its results can be directly applied to either clinical findings or practically used in some one of the vocations of life. In order that the relationship between blind flying and the research accomplished may be understood, it is essential to know what blind flying is. Blind flying is that flying accomplished in which any visible reference to the earth for the purpose of recognition of position is impossible by reason of fog, storms, dust, complete darkness, thick clouds, etc.

(2) *Simulated blind flying.*—Simulated blind flying is that flying in which visual reference to the earth for the purpose of recognition of spatial position is limited to the pilot's cockpit and its equipment by means of proper coverage of the cockpit. Simulated blind flying is that flying accomplished by visual reference to the instruments installed in the airplane; therefore, the proper term is "instrument flying" or, as it is expressed by airmen, "flying under the hood."

d. Efforts to fly.—Since the beginning of time and until recent years mankind has traveled almost entirely on the surface of the earth or the oceans. Man's invasion of the air began when small animals attached to balloons were sent into the air to ascertain if life were possible above the earth's surface. They all returned safely to earth, with the exception that one suffered a broken leg, thus establishing the fact that this contemplated flying era would produce its category of ills and problems for the doctors to treat

and solve. From this time to the epoch-making flight of the Wrights at Kitty Hawk mankind continued his efforts to fly. From the Wrights at Kitty Hawk to the present space-annihilating airplane is a long way in terms of transportation. It has been a much longer way in terms of adapting the human body to the changes and the solution of the medical problems presented.

e. Special senses.—The present generation is the first to move freely in three dimensions as do the birds and fishes. The evolution of mankind had reached a more or less fixed stage when aviation was born, and, as flying was not concerned in this evolution, mankind developed into an "earthbound" entity. Every human being, in arriving at his present state, has had one common factor in his development—contact with mother earth. Individually each is nothing more than the sum total of his experience stored up in the brain, plus the body he lives in. These experiences are obtained for storage as the result of the action of our special senses: sight, hearing, smell, taste, and touch. Two more, vitally important to the aviator, are muscle sense and vestibular or kinetic-static sense.

f. Function of senses.—Stimulation of any of these senses arouses action, and action eventually results in consciousness, a knowledge of environment, and a perception of the physical facts constituting that environment. It is apparent that all stored up experience has had a common stimulator, contact with the earth and its material objects. Experience, based on special senses, has taught one how to adjust himself to various environments. The lessons learned from experience are indelibly impressed in the consciousness. One of the earliest lessons learned is how to maintain equilibrium. Undoubtedly equilibrium is a bodily function maintained by the action of all of the special senses. Some of these senses enter very little into this maintenance; taste, smell, and hearing have little, if any, effect; tactile sense or touch, used in connection with muscle sense, has a little more effect. Chiefly, if not entirely, our equilibrium is maintained by means of a coordinated cooperation of sight, muscle sense, and vestibular sense. By the use of this "trinity sense" one is able to maintain and realize position, rate, and direction of motion, and generally orient himself in relation to the earth.

g. Equilibrium.—(1) Man's equilibrium *on the ground* consists of the ability to maintain his body in any position it is possible or desirable to put it. Man's equilibrium *in the air* consists of the ability to maintain an airplane, which he has become a part of, in any position it is possible or desirable to put it, *plus* the added factor that all *contact* with the earth is entirely lost except for two things, sight

and the column of air the plane is flying in. Human sensations, reactions, and consciousness having developed after countless years of contact with the earth, it is not possible for man to invade the air and safely function using the prior experiences stored up in his brain by a set of special senses evoluted in contact with the earth.

(2) Stabilized equilibrium, either in the air or on the ground, is maintained only when each of the trinity of senses—sight, muscle sense, and vestibular sense—functions correctly, and their stimulations are *correctly interpreted by the brain.* Some equilibrium and orientation may be present with all three imperfectly acting. Adjustment to environment will take place if two remain unimpaired. The combinations of impairment, function, and adjustment are many. All compensatory equilibrium or adjustment to environment, however, has been developed on the ground, and in taking to the air we separate ourselves from the universal common factor, earth contact, and attempt to function with a set of senses and stored up experience developed for earthbound use only.

h. Interpretation of senses.—Since time began human beings have been receiving sensations in their brains and storing them away for future use and guidance when the same situation again arises. In the process of storing away these sensations the brain has accomplished many seemingly weird things. The image of objects on the retina is upside down; yet the brain properly interprets, and we actually see right side up. That portion of our equilibrium sense having its origin in the vestibular apparatus is stimulated into action by body motion. This may be accomplished by motion of the body itself or motion of any object with which the body is in contact. This moving body need not be in contact with the earth to have this sense stimulated into action. One walks, runs, rides a merry-go-round, rides in an airplane, and by use of equilibrium sense is able to maintain any possible or desirable position. Although the three senses—sight, muscle sense, and vestibular sense—are bound into one combination sense (the equilibrium triplets), each of them may be brought into separate action, and send its messages to the brain. One can "muscle sense" his position without sight. He can "sight" his position without the aid of the others. Acting alone, the "vestibular sense" will give the brain information regarding motion, rate of motion, and direction of motion.

i. Reliability of equilibrium triplets.—(1) Sight is the reliable one of the "triplets." "Muscle sense" is an alert, variably acting "triplet." The bad actor of the three is the vestibular sense. This sense, constantly alert, delicately sensitive, and easily stimulated

into action, must be continually checked up on and kept under control by the other two of the combination if proper and continuous equilibrium is maintained. If the body on the ground or the body and an airplane in the air be turned, as in a spin, all three of these senses, acting in coordination, will give *reliable* information regarding body motion and position both on the ground and in space. Ground equilibrium and spatial orientation will be complete.

(2) Sight is the same in the air as on the ground. Muscle sense (the so-called seat sense of the airman) cannot be as good in the air as on the ground, having been developed by years of contact with the earth and its material objects. Automatically on taking to the air one is robbed of a great portion of his muscle sense. All airmen have developed "seat sense"—some to a high degree, and most of them have that essential thing, "the feel of the ship." No false impressions are received from sight and muscle sense. They may be much lessened in case of lack of proper vision or poorly developed muscle sense. Their messages to the brain, whether jointly or separately, are reliable. This is not true of the messages received from the vestibular sense. If your body is rotated in any dimension of space, certain definite and fixed messages will be sent the brain by the vestibular sense acting in coordination with sight and muscle sense. Provided this body motion is not so violent or long-continued as to produce loss of perception, the brain will receive reliable information from this trinity of senses and one will maintain his equilibrium and know accurately at all times what position his body occupies with relation to the earth's surface and in what direction, if any, it is moving. If, during this rotation, the body is stopped or retarded, one will have a momentary sensation of giddiness, but will immediately, by the use of sight, adjust himself to the earth (gravity) and maintain equilibrium.

(3) Whenever the human body is rotated in any dimension of space, with the eyes closed, thus removing vision from the trinity of sight, muscle sense, and vestibular sense, and this rotation is retarded, stopped, reversed, or continued until rotating body motion is coincident with the motion of the fluid in the vestibular (semicircular) canals, just as definite and fixed messages will be sent the brain as if the eyes were open and vision intact, but each and every one of these messages will be false. One will be able to *correctly* interpret the original starting motion only. He will recall that the vestibular apparatus is primarily composed of three tiny sets of fluid-filled canals placed at right angles to each other in the

labyrinth, in the sagittal, coronal, and horizontal planes, thus providing motion-sensing in any dimension of space.

j. Experiment.—Now consider a practical experiment in order to visualize what happens when vision is absent and the body is rotated. Any smoothly running revolving mechanism will do. A barber chair is ideal. Flight surgeons use the Jones-Barany chair. In such a mechanism only right or left rotation is possible; therefore only the action of the horizontal motion sensing vestibular canals can be demonstrated in this chair. In an orientator any of the spatial positions may be assumed, and the corresponding canals tested. The results are the same in any case. If there is such a thing as acquiring immunity, the horizontal canals, being the ones in constant daily use, should be less sensitive than the others. It was found that there was no difference, and that constant use did not affect the sensitivity. With the eyes covered, rotation at any average speed is started. One will immediately and correctly interpret right or left rotation Having always experienced this same sensation during prior experience of body motion to the right or left, one will be positive as to what is happening. The number of rotations should be limited in order that too violent reactions will not be produced. If on the sixth to eighth rotation the motion of the chair is now *retarded* to a slow speed, one will have an immediate sensation of turning in the opposite direction, and a message will be sent the brain to that effect by the vestibular apparatus, which is now acting without its "control coordinator," sight. One will be positive his body is now turning in the opposite direction of prior motion. If the rotating chair is now *stopped*, the *sensation* of opposite turning will be much intensified. This sensation of opposite turning will last from 5 seconds to as high as 25 seconds in some individuals. The average is about 23 seconds. This average was established after examining hundreds in the Jones-Barany revolving chair during the research conducted. Every human being has his own individual threshhold of vestibular stimulation and reaction.

If the rotation of the body is *continued* (usually 8 to 10 turns) until the motion of the body and the motion of the fluid in the semicircular canal being stimulated is the same speed, the vestibular sense will apparently be put out of action and the brain will receive an immediate message that all motion has ceased and that the body is sitting still.

k. Vertigo.—Repeated reversal of rotation, without stopping, creates an utter confusion of motion sensing. What has happened? Vertigo (to turn or turning) has been produced. Vertigo consists

of two things, a sensation of turning in the *opposite* direction to prior motion, and a sensation of falling in the same direction as prior motion.

Vertigo is medically defined as "the subjective sensation of a disturbed relationship in space."

l. Effect on flying.—It will now be realized that the pioneer aviator dependent on messages sent to his brain by his vestibular sense, acting without the "control coordinator, vertigo stopper" sense of sight was in a dangerous predicament.

The above is exactly what happens in blind flying. All visual reference to the earth or any object the prior position of which in relation to the earth's surface is part of the consciousness is absent, and only muscle sense and vestibular sense remain. As a matter of fact, a real blind man would function better in this predicament, because after all there is no difference in not being able to see *anything* and not being able to see, except that the real blind would have usually developed compensatory equilibrium to a high degree.

m. Immunity.—All of the published literature and the research work accomplished prior to 1926 concentrated on one idea, the finding of a way of producing immunity against vertigo by means of placing pilots in a freely movable, revolving apparatus, and turning their bodies through the various spatial positions in the belief that constant repetition of motion would establish an immunity. Every old-time pilot has had "a ride" in the Jones-Barany chair and most of them have spent hours in some type of revolving orientators. Nothing came of all this except to establish the fact that pilots who could expertly handle an orientator were possessed of a high degree of muscle sense and a keen sense of perception. No immunity was obtained against the reactions experienced in that deadly enemy of the airman—the spin. No immunity was possible from a physiological or a technical standpoint because no research or experiment conducted had arrived at a solution of the problems involved. There was no scientific basis established on which to build instructions to airmen in the practical application of these perfectly normal physiological reactions experienced when doing blind flying.

n. Vertigo as an entity.—Vertigo is one of the oldest symptoms found in medical literature and when clinically present is believed to have a pathological basis. No study of vertigo as a purely physiological entity, to establish it as a *causative factor* in the behavior of human beings in their adjustments to their environment, has been found in the medical literature prior to 1926, and none is believed to exist. *Induced* physiological vertigo (that is, vertigo without

pathological basis) may be a common causative factor in human behavior in vocations other than flying. The automobile, swiftly and freely movable in any horizontal plane, subjects the occupants to many of the factors that tend to produce "induced vertigo."

o. Universality of reactions.—All vertigo reactions follow certain definite and fixed lines and all humans are subject to the same reactions varying only in intensity. A human being in whom these reactions are absent or distorted is abnormal and has either met with a physical disaster or was born without properly functioning sense apparatus. In such cases some of the normally acting senses must compensate for this lack in order that the individual may avert disaster and simulate normal control in following the ordinary routines of life.

p. Aviation history.—In order to understand how and why this research was started it is necessary to digress into aviation history.

From the beginning of man's invasion of the air, fog, the universal menace to travel of all kinds, has taken a great toll of human life. Old-time pilots learned to fly without artificial instrumental aids of any kind, and developed to a remarkable degree what was called "flying sense." Until long after the War flying for any length of time without sight of earth or sky was impossible.

About 1918 a "turn" indicator was invented. Since that time many artificial aids to spatial orientation have appeared. Bank-and-turn indicators, artificial horizons of various types, flight integrators, etc. All of these instruments are gyro-controlled to overcome the pull of gravity and allow their "indicators" to show ship movement and spatial position. Two of the common ones in use are illustrated in figure 3.

The Sperry artificial horizon consists of a miniature gyro-controlled airplane which will assume the position of the carrying plane while in flight. The pilot controls the position of his airplane by visualizing what the miniature plane is doing, and correcting his position accordingly.

The bank-and-turn indicator mounted at bottom has a pointing arrow which indicates all turns of the plane, and a small ball, seen in the runway at the tip of the arrow, which moves from side to side when the plane is banked up in a turn to right or left. Every artificial aid to spatial orientation lets the pilot "mentally" keep one foot on the ground.

The original intent of these instruments was to improve technical flying ability by showing pilots when smooth turns and banks were being made and to function as a crutch to the magnetic compass. All

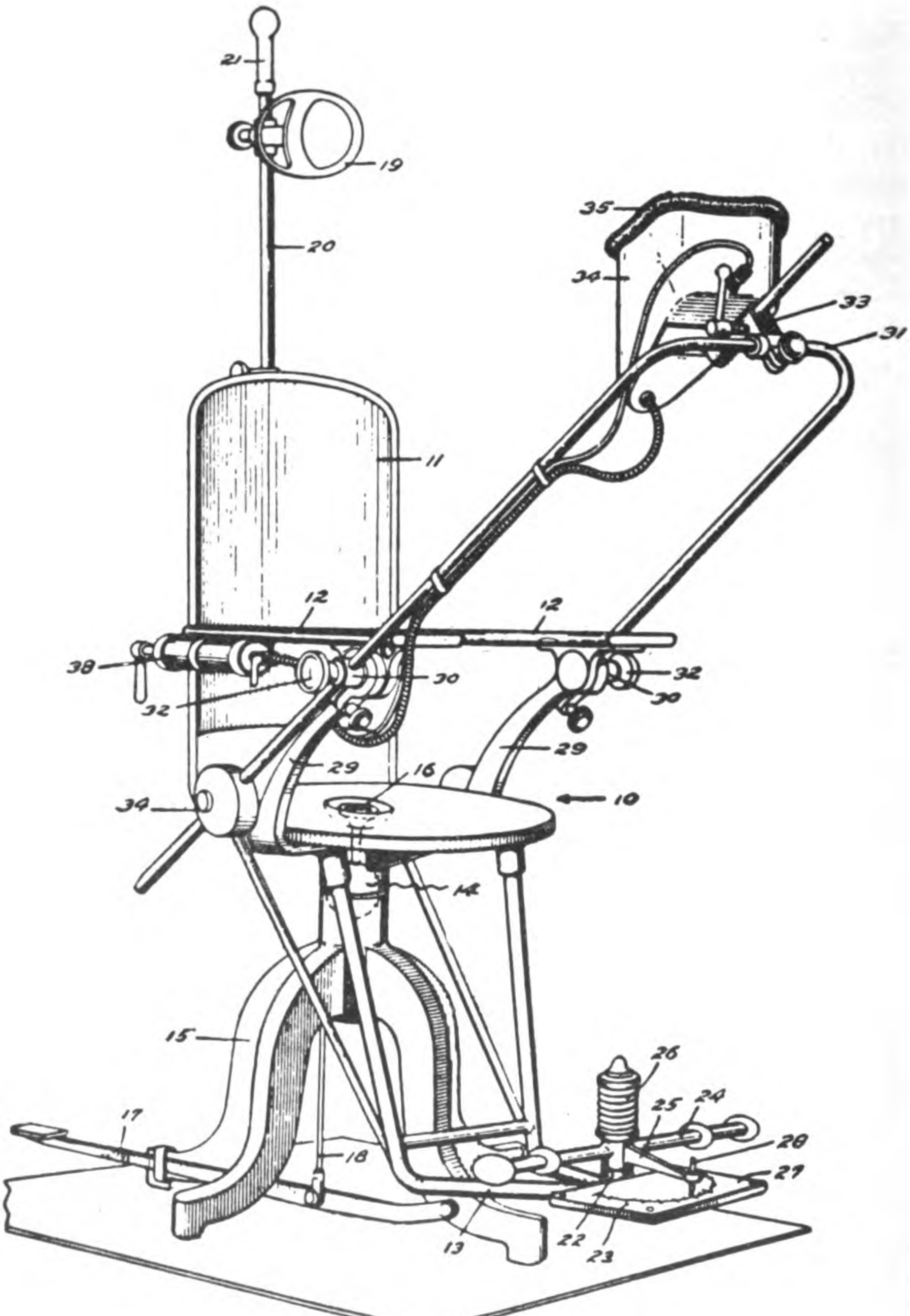


FIGURE 3.—Spatial orientation indicators.

of the old-timers were, however, taught to fly by instinct, and the terms "inherent flying ability," "seat sense," and "flying sense" came into use. Artificial aids showing them when their ships were turning or banking were considered as entirely useless, as all they had to do was look at the earth and see what their plane was doing. So, although all planes were later equipped with indicators, they went unserviced and unused. Unfortunately for many, the visibility did not always stay good on every flight, so that pilots could look overboard at God's horizon and see what their ships were doing. When visual contact with the earth was obliterated they discovered that it was impossible to maintain their planes in the air. If the fog was not completely on the ground, they would come down under it and "hedge hop" over trees and houses in a desperate attempt to keep visual contact with the earth until they could find a place to land. Only extreme skill and good luck brought many of them through. If the fog was completely on the ground, the only alternative was to climb high above possible danger. This was little comfort, for there is the disturbing knowledge that when the ceiling is reached the fuel may be gone and the plane must come down. Flying in fog without proper navigation instruments, the pilot will become hopelessly lost from a directional standpoint.

q. Flying in fog without instruments.—Flying in fog without a visual reference to gravity (the earth), such as a bank-and-turn indicator, or some form of artificial horizon, the pilot will be unable to sense the position of his ship with relation to the earth's surface, unable to sense the speed and direction of motion and will eventually go into circular motion, experience the vertigo described, and crash unless he takes to his chute before volitional control is lost.

r. Instrument flying.—Blind flying is the grim specter of aviation. The remedy for all this is to practice simulated blind flying under the hood until instrument flying is as easy as flying under clear skies and with perfect visibility. About 1919 the Air Corps advocated the use of any instruments that would add to the safety of flying, and there was a revived interest in various flying instruments. However, no progress was made until 1926.

A report made by Donald E. Keyhoe in 1929 follows:

* * * Full credit must be given these men (pilots) who have tested the various instruments and methods suggested by scientists. The invention of the bank-and-turn indicator was the first step. But the pilots who first used it tried different methods without instruction, so few became expert. Those who succeeded were able to go through fog or snow for 20 or 30 minutes and at the end of that time their strained nerves would stand no more. Sight of ground or sky became vitally necessary to clear away the confusion that was swiftly taking control.

Two men were mainly responsible for progress beyond this stage. Ocker and Myers proved that this strain was caused by the pilot's disbelief in his instruments and a strong tendency to trust his own senses, which are alway misleading. The Ocker-Myers method takes into account the three elements which give balance: muscle sense, sight, and vestibular sense. * * *

s. *Overconfidence.*—There is a tendency in an occasional young aviator to become so cocky over his flying ability that it becomes necessary to partially deflate it for his own safety. For many years the following plan was used in such cases: they were placed in the Jones-Barany revolving chair and turned right or left and asked which way they were turning. Their replies were naturally correct. Their eyes were then covered and the rotation repeated. After a few turns the chair was gently stopped and they were asked which direction they were turning. Vertigo having been induced, their replies were invariably that they had started to turn in the opposite direction of prior motion. The eyes were uncovered and to their amazement the chair was not turning at all. If this did not quite satisfy them, the rotation was continued until they experienced the sensation that the body was not moving. On being uncovered and finding they actually were turning right or left their chagrin was very evident. For an aviator to suddenly discover his inability to tell which way his body is turning, if at all, is, to say the least, disconcerting.

t. *Origin of research.*—In January 1926 this induced vertigo test was given to an old-time pilot. Following the test he disappeared without comment of any kind but soon returned with the view box (fig. 4) in his hand. The test was repeated in all combinations of rotation, using the unlighted box to cut out the light and thus remove sight from the trinity of equilibrium senses. There was the usual induced vertigo with the usual inability to correctly tell which way his body was turning, etc. The gyroscope was then started and the bank-and-turn indicator put in action. The flash was lighted and the tests repeated. This time every answer was correct as to direction of motion, stopping, and starting. Even the confusion of reversals was absent. The sensations were felt the same as before; but by giving the answer shown by the pointer on the bank-and-turn indicator, instead of the answer prompted by his senses, it was found impossible to confuse him. This demonstration started the research into blind flying. It was immediately recognized that here was the answer to pilot's inability to do blind flying without a visual reference to gravity.

u. *Bank-and-turn indicator.*—By lighting the box the equilibrium trinity senses was restored to a coordinated action. Merely restoring

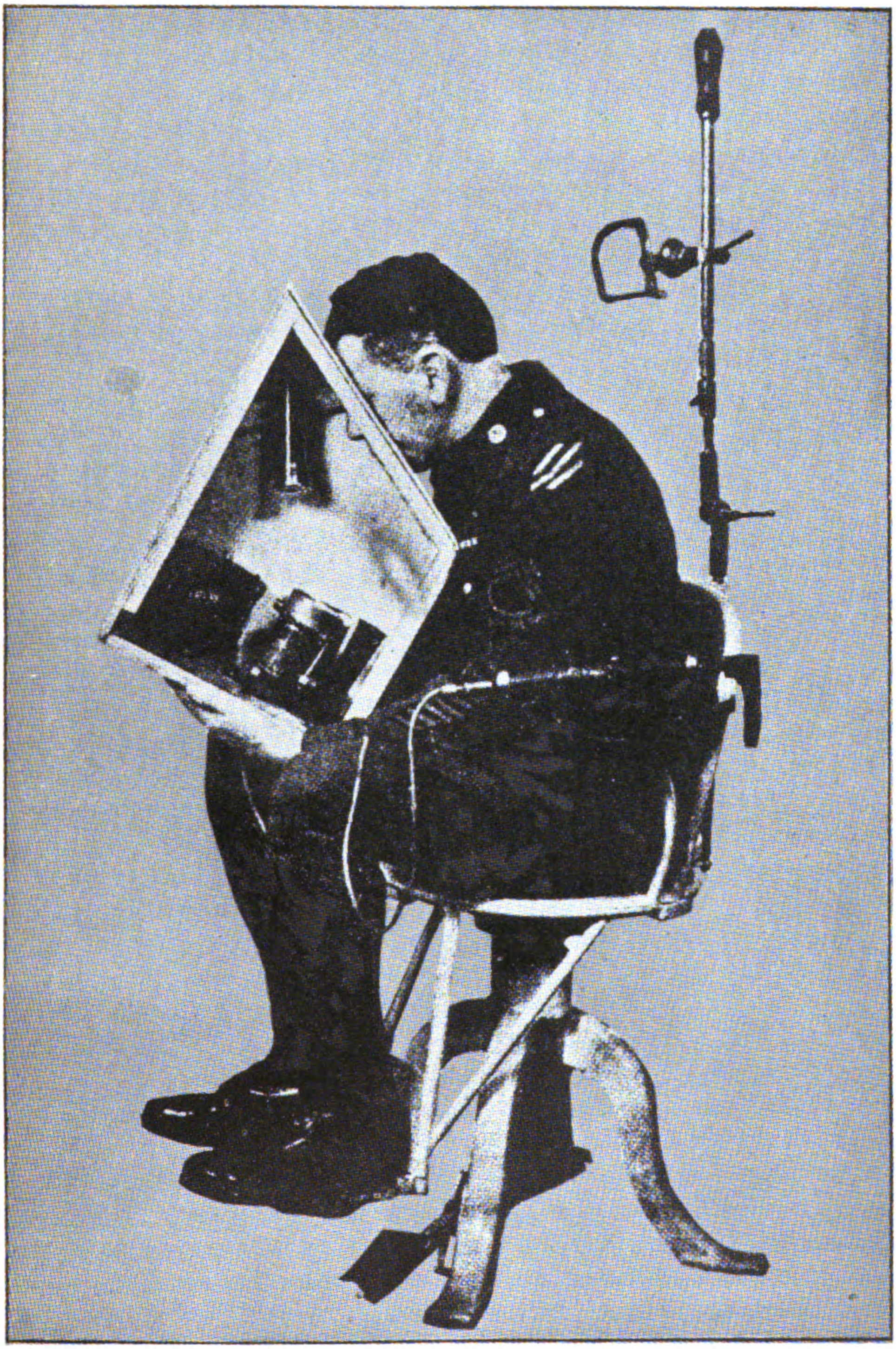


FIGURE 4.—View box.

sight to the equilibrium sense, however, is not enough. There must be something within the pilot's range of vision that will act as a *vertigo* stopper and tell him what position his ship is in with relation to the earth. In other words, allow the pilot to mentally visualize "where the ground is." The hand on the bank-and-turn indicator will accurately show motion in either direction, right or left, and will come to a dead center and remain there when there is no rotation. There will be the same false impressions of reversal of movement and falling received by the brain following the rotation; but by means of sight one will be able to correct these false impressions of movement and vertigo will be almost immediately overcome, *provided* one believes the instrument.

v. Importance of discovery.—That there was any connection between the normal physiological reactions of a pilot and his lack of ability to do blind flying had not been considered until experience with, and belief in, the action of the bank-and-turn indicator crashed head-on into the knowledge of induced vertigo and the physiological reactions involved in the special senses concerned. Out of the wreck emerged several things of vital importance to aviation.

w. Foundation sense.—The foundation sense of all spatial orientation is vision. There is no substitute for visual reference. It makes no difference what the pilot sees so long as it gives him that vital information, "Where is the ground and what is the position of the airplane with reference to it." Many accidents have resulted from ignorance of this vital fundamental factor. Many have resulted because there were pilots who knew they could do blind flying by using their "flying sense." There is no longer any excuse for ignorance regarding blind flying. Without exception the present day pilot who can do so obtains training in instrument flying. This is a far different reaction than the general attitude of most aviators when it was announced, in 1926, that "no one could do blind flying without artificial aids" and that it had been "discovered how to do it." The idea was promptly labeled as being enthusiastically crazy.

x. Flying sense.—In the past those pilots who had discovered they could not fly blind did so through bitter experience. They, however, had nothing of value to report as an aid to their fellow pilots. They merely labeled themselves as better fliers than the average. However, it was noted they avoided fog flying. Having been taught to fly by instinct it was hard to convince the average pilot that his flying sense would not bring him back from every flight.

A knowledge of the uses of any one of the special senses and the care of and our reactions under all conditions toward these special

senses become of vital importance and value only to the individual making special and expert use of that special sense.

The airman being vitally concerned in his ability to sense his position, change of position, and relation to the earth's surface, has called all his special senses into play and has developed "flying sense."

What is flying sense? It is not an inherent sense. It is an acquired sense. It is something the airman has that others do not. In its entirety it is composed of the special senses of sight, hearing, taste, smell, touch or tactile sense, muscle sense, and vestibular or inner ear sense.

Just as there are degrees of "doctor sense," there are airmen with varying degrees of "flying sense." Being an acquired sense and dependent for its development on the ability, adaptability, aptitude, and knowledge of the person, it is evident that, everything else being equal, the airman who correctly understands and interprets the sensations received from his various senses will have the most "flying sense."

y. Reactions in air.—Constant repetition of demonstrations with the "vertigo stopper box" finally convinced pilots that it was a real lie detector and that, on the ground at least, they could not tell which way they were turning if they could not see. Many continued to fly by instinct in the stubborn belief that these "reverse" reactions could not happen in the air. In answer to this a covered cockpit ship with one exposed control pilot seat was devised and many hours were spent testing out the various reactions of pilots. It was proven beyond a doubt that these reactions do take place in the air and, in addition, are much intensified.

Later the findings were communicated to the National Advisory Committee for Aeronautics and elaborate flight tests were made with a covered hood and a control pilot. Their findings verified the theory that circular movement invariably resulted during flights made by a pilot flying in a totally dark cockpit. These findings verified our original contention regarding movement and the production of induced vertigo. Carroll and McAvoy published the following conclusions:

> Many pilots have felt that the flying sense was largely one of muscular balance and that visual reference played a more or less insignificant part. These experiments should serve to remove this idea and develop the appreciation of the fact that muscular balance plays an extremely small part in flying, excepting in correlation with visual reference in the development of a polished technique. Visual reference of some sort must be provided, either by the horizon, by the reflection of the sun or moon while in dense fog or clouds, or by proper instrumental equipment.

The fact should not be neglected that the use of proper navigational instruments provides an artificial horizon, if not in a single instrument, then in the correlation of several instruments, such as a turn-and-bank indicator and an air-speed meter.

It can be recommended to all pilots that a careful self training in the use of and reliance on navigational instruments of this character will provide them not only with definite mechanical assistance, but likewise will go far to remove the psychological hazard of blind flying.

z. Spiral movement.—Many years ago experiments were conducted with blindfolded individuals and proved conclusively that spiral movement always resulted when running, walking, swimming, driving a car, etc. Continuing the experiments on the lower forms of life it was concluded that any forward-moving organism (including man) would move in a spiral path provided no orientating sense, such as sight, touch, etc., guided it.

aa. Value of view box.—The value of the Ocker-Myers view box became generally recognized as the only available means of instructing pilots and prospective pilots while on the ground in the sensations they would experience and the reactions they would have if they attempted to do blind flying without an artificial horizon.

ab. Artificial horizon.—The term "artificial horizon" was originated and given the following definition in the original report:

Any instrument or combination of instruments that will *quickly*, *easily*, and *reliably* give the pilot information that he may mentally visualize in terms of where is the ground.

ac. Reference.—In the United States Air Service magazine, issue of April 1928, there appeared an article, "The Artificial Horizon Seeks Recognition," by Frederick R. Neely, in which the research conducted was fully explained.

ad. Results of research.—Instrument flying and simulated blind flying were the logical outcome of this research work, because there had been established the physiological foundation on which to build the technical superstructure. The device (except chair) illustrated in figure 4 was originated and a course of ground instruction in blind flying was formulated which was adopted by the Air Corps as routine in May 1934. In addition, a routine course in actual instrument flying follows the ground instruction.

ae. Function of demonstration box.—The Ocker-Myers demonstration box is based on sound physiological fundamentals and its value as a preliminary to actual instrument flying in an airplane is essential because only in this way can the student be actually shown that he cannot depend on his own sensations when God's horizon is not available.

af. Developments.—The problem of how to keep the pilot in the air when he did not have a horizon to look at having been solved, it became necessary to solve the problem of guiding him to his intended destination and safely landing him on an airport he could not see. The development of blind take-off, blind navigation, and blind landings was much stimulated by the discovery of the basic fundamental factors underlying blind flying. Today they are accomplished facts.

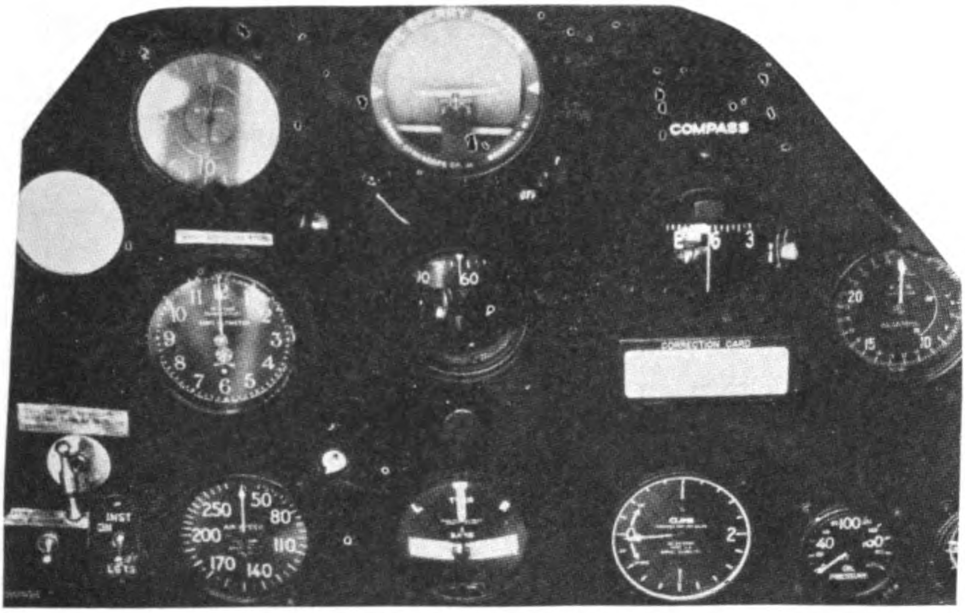


FIGURE 5.—Instrument board of blind flying ship.

ag. Key to problem.—If this type of flying is participated in for a length of time sufficient to train the pilot in automatic control he will finally become as proficient as if he were flying in ideal weather. The successful blind flier must correlate his senses to his instruments.

SECTION XI

MISCELLANEOUS EAR CONDITIONS

63. Costen's syndrome.—*a. History.*—These neuralgias and ear symptoms associated with disturbed function of the temporomandibular joint were first proposed as a symptom complex in 1933. At

that time, it was considered to be of infrequent occurrence, but since then a rather large number of cases have been observed and the condition may now be considered quite common.

b. Cause.—The chief function of the jaw is mastication, and it is equipped with powerful muscles, the masseter, the temporalis, and the pterygoid internus, which act to close the jaw. Most of the action of closure is brought against the posterior third of the jaw and so, when the molar teeth are missing or the grinding teeth are reduced in size, the mandibular joint is liable to destruction. Anatomically, the symptoms resulting may be explained by—

(1) Erosion of the bone of the glenoid or mandibular fossa and impaction of the condyle against the thin bones separating them from the dura.

(2) Irritation by the uncontrolled movements of the condyles backward or mesially, of the auriculo-temporal nerve.

(3) Production of reflex pain and sensory disturbances in the various connections of the chorda tympani nerve, the condyle irritating it where it emerges from the tympanic plate at the mesial edge of the glenoid fossa through the petrotympanic fissure.

(4) Compression of the eustachian tubes; in overclosure of the joint, the tensor veli palatini muscle bordering the membranous anterior edge of the tube and the adjacent spheno-meniscus muscle are seen to wrinkle and crowd the eustachian tube, closing it firmly. Normally, during the act of swallowing the tensor palatini muscle should be tensed and effect a temporary opening of the tube.

c. Symptoms.—The following symptoms either singly or in combination are found in this condition:

(1) *Ear symptoms.*

(*a*) Intermittent or continuously impaired hearing.

(*b*) Stopping or "stuffy" sensation in the ears, marked about mealtime.

(*c*) Tinnitus usually low buzz in type, less often a snapping noise while chewing.

(*d*) Dull or drawing pain within the ears.

(*e*) Dizziness, with nystagmus.

(2) *Pain and irritative symptoms.*

(*a*) Headache about the vertex and occiput and behind the ears, increasing toward the end of the day.

(*b*) Burning sensation in the throat, tongue, and side of the nose.

(*c*) Dry mouth with almost total absence of saliva; rarely, excessive saliva.

(*d*) Occasional herpes of the external ear canal and buccal mucosa, most marked on the edentulous side.

d. Treatment.—The treatment of these cases is reposition of the mandible by opening the bit, increasing the vertical dimension, and correcting the malocclusion.

64. Tinnitus aurium.—*a. Description.*—Tinnitus aurium is a subjective sensation of sound in one or both ears. It is a common symptom of aural disease. It is sometimes divided into two types: *external*, produced in the middle ear by actual stimulation of the tympanic membrane; *internal*, beginning in the labyrinth and created by some upset of metabolic equilibrium or disease of the nerves, cerebrum, or associated organs.

Tinnitus may or may not be associated with deafness. The sounds may be constant or intermittent and the severity may increase or diminish. It may precede or follow the onset of deafness and may be associated with dizziness or staggering.

The noises may be simple or complex and vary in character and intensity. They are described as hissing, whistling, humming, rustling, burring, blowing, ringing, clicking, shrieking, jangling, roaring, rumbling, and rasping. Occasionally they may have the form of a specific tune.

b. Classification.—Tinnitus is sometimes classified according to the underlying lesion or disorder:

(1) *Obstruction sounds.*—Noises due to occlusion or impaired motility of some portion of the sound-conducting apparatus.

(2) *Labyrinth sounds.*—Noises due either to structural changes in the cochlea or to alterations, either increase or diminution of the intralabyrinthine pressure.

(3) *Neurotic sounds.*—Noises due to abnormal instability of the auditory nerve.

(4) *Cerebral sounds.*—Noises due to abnormal conditions acting upon the auditory centers in the cerebral cortex (auditory hallucinations).

(5) *Blood sounds.*—Noises produced by the blood currents in vessels in or near the ear and due either to disturbances in the local or general circulation or to abnormalities in the size, shape or position of the vessels.

The first four types will cause a subjective tinnitus, while the fifth type may be both objective and subjective.

65. Meniere's symptom complex.—*a. History.*—In 1860 Meniere reported a case of spontaneous hemorrhage into the labyrinth. In his report he gave a clear picture of the symptoms which accompany

recurrent aural vertigo. There has been some confusion as to the terminology and it is generally conceded that the term "Meniere's disease" be used to define true cases of the rare labyrinthian hemorrhage and "Meniere's symptom complex" or "Meniere's syndrome" be used in cases of recurrent aural vertigo.

b. Symptoms and characteristics.—This condition is characterized by the following symptoms:

(1) A sudden onset in a previously healthy auditory apparatus.

(2) Vertigo, uncertain gait, rotations, and falling associated with nausea and vomiting.

(3) Tinnitus, continuous or intermittent.

(4) Deafness, unilateral and progressive. Occasionally hearing may be suddenly completely abolished.

In a few cases there occurs in the attacks a transitory loss of vision and diplopia, and cases in which loss of consciousness occurs have been noted.

These attacks are recurrent, the period between the attacks varying from weeks to years. These attacks are so distressing that even the symptomless intervals are marred by the dread of their recurrence.

The disease is one of middle life and affects males more frequently than females. There is a tendency for the process, whatever it may be, to progress for several years until the function of the ear is lost.

c. Cause.—The cause of the condition is unknown; the following causes having been suggested by various authors:

(1) Local infection.

(2) Allergy.

(3) Lesions of the auditory nerve.

(4) Cyclic changes, either chemical or physical, in the endolymph.

d. Treatment.—There have been many types of treatments advocated, and the following have met with some success:

(1) *Surgical.*

(*a*) Section of the vestibular fibers of the VIII nerve.

(*b*) Alcoholic injection of the labyrinth.

(2) *Dietary.*—The use of a salt-free diet with addition of massive doses of ammonium chloride.

66. Labyrinthitis.—*a. Recognition.*—The symptoms are so severe and the findings so positive that the question of labyrinthitis in the examination of applicants for flying training presents no difficulties. Also, it is most unusual to have a case of involvement of the labyrinth without an accompanying deafness of the involved ear.

Labyrinthian disorders will occasionally occur in the active personnel, and a brief description of types, causes, and symptoms is indicated.

b. Sources of infection.—True infection of the labyrinth with pyogenic organisms occurs from three sources: metastitic, meningeal, and tympanic. The meningeal source is usually associated with cerebrospinal meningitis. The tympanic cases are usually by direct extension from acute or chronic suppurative otitis media, or mastoiditis. Labyrinthitis is said to occur in about 1 percent of cases of middle ear suppuration. The end results may vary from recovery with normal function to complete destruction of the labyrinth.

c. Symptoms.—The symptoms consist of—(1) *Vestibular nystagmus* (slow movement in one direction and a quick movement in the opposite direction).—This nystagmus varies from the mild type, in which the movement only occurs when the eyes are directed in the direction of the quick movement, to the type in which the nystagmus persists no matter where the eyes are turned.

(2) *Vertigo.*—Rotary in character with the subjective impression that the surrounding objects are rotating in the plane of the nystagmus. There is a tendency of the body to fall in the direction of the slow component.

(3) *Nausea and vomiting.*

(4) *Tinnitus and deafness.*

Cases show great variations in the types and severity of the symptoms. One recent case showed only nystagmus when looking toward the direction of the quick movement, and complained only of a feeling of "lightness" in the head and a tendency to fall to the left.

d. Tests.—Vestibular tests should not be made during the acute stage of the disease, but on subsidence of the acute attack, the vestibular reaction will usually be absent.

e. Other cases with similar symptoms.—Labyrinthian symptoms are seen in cases other than those with suppurative labyrinthitis and many causes are given. All may produce typical findings:

(1) Cold, heat, and sunstroke.

(2) Hyperemia or hemorrhage into the labyrinth.

(3) Sudden changes in pressure in the middle ear, seen in divers and aviators.

(4) Mechanical disturbances produced by movements, airsickness, trainsickness, seasickness, and swingsickness.

(5) Drugs: alcohol, quinine, tobacco, morphine, and salicylates.

(6) Detonations and shock, probably by sudden changes of pressure in the middle ear.

(7) Repeated loud noises.

(8) Mental disturbances, such as fright.

(9) Injuries to the labyrinth, such as may occur while doing a paracentesis or from penetrating wounds which strike the labyrinth.

(10) Focal infection, toxemia, circulatory disturbances.

(11) Associated with other diseases such as syphilis, exanthemata, nephritis, mumps, leukemia, and others.

f. Airsickness.—Airsickness is a major problem, as many cadets are unable to continue training because of the severity of the attacks. So far it has been impossible to tell which men will be airsick. Labyrinth tests usually do not give any reliable findings. Probably a truthful history of train or swingsickness would be indicative, but such histories are difficulut to obtain, as young men are as a rule somewhat ashamed to admit these defects. Most probably airsickness is a complex reaction to the consciousness of disordered orientation of the body in space and results from a combination of causes, ocular, vestibular, cerebellar, cerebral, and psychogenic, particularly the feeling of anxiety, combined with an overactivity of the sympathetic nervous system.

67. Deafness in aviators.—*a. Terminology.*—It has been noticed for many years that the older pilots have a diminished auditory acuity. This condition has sometimes been called aviator's deafness. Liberty Motor deafness, flying deafness, and aero otosclerosis. It is doubtful that this condition warrants a specific name.

b. Causes.—The diminished hearing is due to a number of causes:

(1) Repeated exposure to noise of high decibel rating of fairly constant pitch over prolonged periods of time. After riding in an open airplane for any great period of time, one is more or less deaf for a subsequent variable period of time. Repeated exposures tend to cause this temporary condition to become permanent. Several theories as to the cause of this type of deafness have been given, but it is probable that it results from derangement or injury to the external hair cells of the organ of Corti.

(2) In addition to this cause, the factors mentioned in section V must be added, and, of course, these factors are variable in different individuals.

(3) Of late years the widespread use of radio has added still another insult to the auditory apparatus, and it is still too early to say what the final result of this additional factor will be.

c. Incidence.—(1) *Past.*—It is noted clinically that the deafness in any marked degree has occurred in the older pilots, particularly some of the wartime pilots, one of the reasons for this being the general reduction in auditory acuity that occurs in age. However, other conditions must be considered. These pilots flew in ships with cockpits which were very little protected from the slipstream. The engines with open stacks were either directly in front or directly to

the side and very close. Furthermore, they did not know or did not use prophylactic measures such as plugging the external auditory canals with cotton or other material and the maintenance of middle ear pressure equilibrium during ascent and descent.

(2) *Present.*—At the present time we find many younger pilots who have more air hours than the older pilots who show little or no decrease in auditory acuity. This is due to the better construction and protection of the cockpit, change in type of engines used, greater distance from engine to pilot, streamlining with decrease in structural noises, decreased vibration, and a better knowledge of prophylactic measures.

(3) *Future.*—With increasing refinements in engineering and noise control, it is to be expected that the deafness of aviators will gradually decrease so that their auditory acuity will be but little below that of other males of the same age group. In the meantime, it is essential to select only those with good hearing as applicants.

d. Mixed type.—As a rule the deafness noted in the pilots is of a mixed type—diminished reception of the low tones with a marked decrease or even total loss of the notes above 2048 D. V. This type of hearing curve is to be expected for a condition resulting from both a conduction and a perception deafness. It is interesting to note that the right ear is usually more involved than the left.

68. The "leans."—This is a term used by some pilots to describe an interesting reaction to a disordered orientation of the body in space. The phenomenon occurs following prolonged flights by instruments, and is described as being a feeling that the ship is flying in a banked position. The degree of lean is variable in different individuals and at different times, the length of time varying from a few seconds to 1 or 2 minutes. Either the right or the left wing may seem to be down. Some pilots describe the condition as being merely a momentary disturbance following a turning movement, while others describe the sensation as being very definite, with a strong urge to right the ship. In practically all cases where this occurs the pilots are experienced instrument flyers, and a glance at the instruments, which show level flight, corrects the false sensation.

The condition is important in that if an inexperienced pilot should neglect his instruments and attempt to correct his impression by the use of his ailerons, disaster could easily follow. Most pilots of this day have had instrument-flying experience and have confidence in the accuracy of their instruments. There is, however, a period of transition—that is, in changing from flying contact to flying instruments—when our false physiological conceptions of our position in space are confusing even to some of the best instrument flyers.

Section XII

GENERAL METHODS AND EQUIPMENT FOR EYE EXAMINATION

69. General.—*a. Importance.*—There is no vocation as yet undertaken by man that is so dependent upon "vision" as that of flying. "Reduced to its simplest terms the function of the eye is the light sense. This is the discrimination between light and darkness, and various degrees thereof" (Adler). Going a little further it may be said that "vision" is the proper appreciation of light, of form, of color, and of distance, and we see how all of these are of vital importance to the aviator; and a defect, which may be considered as minor or insignificant in the ordinary walks of life may be serious indeed for the pilot of aircraft.

b. Equipment.—In order that a thorough and intelligent examination of the eye and its adnexa may be conducted, it is essential that adequate and proper equipment is used, and that ample floor space and lighting facilities are available. For certain phases of the subjective examination a dark room of sufficient length to permit a distance of 6 meters between the examinee and certain test objects employed is necessary, and in addition there should be a well-lighted room, particularly for the objective parts of the examination. In the dark room there should be a convenient lamp situated over or near the chair of the examinee, controlled by a switch which is accessible to the examiner. It should be remembered that a conclusion may be arrived at in some instances by two or more methods, and where possible the examiner should verify his findings by two or more methods before making a final interpretation.

c. Accuracy.—In all probability there is no other type of physical examination where the time element is so important and where the adage "make haste slowly" applies more forcibly. A complete ocular examination is at best a tedious procedure and requires an infinite amount of patience on the part of both the examiner and examinee, and where "short cuts" are employed, or decisions made hastily, the accuracy of the findings is at best questionable.

d. Type.—In the examination of applicants for appointment or detail to the Air Corps for flying training, it should be borne in the mind of the examiner that such an examination differs materially from the examination of patients reporting to a clinic for treatment

of some condition that they themselves perhaps have recognized. It is to be presumed that all applicants for flying training are anxious to qualify physically, and in some instances may attempt to conceal or to minimize some ocular defect, provided they are aware of its existence. Therefore, it is not infrequently the problem of the examiner to uncover and recognize defects without the assistance and cooperation of the examinee. For this reason, all phases of the examination should be so conducted that, where possible, findings are based upon objective methods of examination. Obviously, this is not altogether possible. In many instances, however, subjective findings may be checked by objective methods.

e. Phases.—In the examination of the eyes of applicants for flying training in the Air Corps, there are 14 phases or steps toward its completion, and where each phase is carefully and painstakingly accomplished there is little that may be overlooked. It will be noted, and will be explained later, how some of these phases may overlap or be very closely associated with one another. Below are listed these various steps of the ocular examination and the equipment employed. In some instances more than one method may be employed to arrive at one finding, and in such cases those pieces of equipment as are called for in AR 40–110 are mentioned first.

(1) *Visual acuity (right and left).*—Apparatus required: Illuminated Snellen test types at 6 meters, or various modifications of test types incorporated with electrically lighted cabinet or projection device.

(2) *Depth perception.*—Apparatus required: Howard-Dolman depth perception apparatus with proper illumination.

(3) *Maddox rod screen test at 6 meters.*—Apparatus required: Phorometer trial frame equipped with multiple Maddox rods, right and left, Risley rotary prisms, right and left; or prisms, Maddox rod and trial frame from trial lens case; and in either case, whether or not the phorometer trial frame is used, a spotlight 1 centimeter in diameter placed at 6 meters in front of examinee's chair.

(4) *Red lens test.*—Apparatus required: Red plano lens, trial frame, flat surface such as a blackboard, and meter rule.

(5) *Prism divergence.*—Apparatus required: Risley rotary prism in phorometer trial frame, or prisms from trial lens case.

(6) *Associated parallel movements (and tangent curtain).*—Apparatus required: Small test object, as white-headed pin, Bjerrum tangent screen, or blackboard in conjunction with tangent rule, and spotlight as used in Maddox rod test at 33 centimeters.

(7) *Inspection.*—Apparatus required: Adequate illumination, condensing lenses as required for oblique, illumination (from trial

lens case), and, where available, binocular loupe (Beebe), hand slit lamp, ophthalmic lamp, slit lamp with binocular corneal microscope, and electric ophthalmoscope.

(8) *Pupils.*—Apparatus required: Same as for inspection.

(9) *Accommodation.*—Apparatus required: Prince rule with card, or Thorne rule.

(10) *Angle of convergence.*—Apparatus required: Prince rule, or small millimeter rule and small test object, as white-headed pin, and table for computing angle of convergence.

(11) *Central color vision.*—Apparatus required: The Ishihara test, and the Stillings' pseudoisochromatic test and three sets of Holmgren's wools.

(12) *Field of vision.*—Apparatus required: Perimeter with test objects, Bjerrum tangent curtain or blackboard with tangent rule, campimeter if available.

(13) *Refraction.*—Apparatus required: Cycloplegic, retinoscope, trial lens case, and Snellen test types.

(14) *Ophthalmoscopic examination.*—Apparatus required: Ophthalmoscope, preferably electric.

Each of these phases of the examination will be discussed in turn. In many instances references will be made to physiologic optics, physiology, histology, anatomy, and pathology of the eye in explanation of the procedure of the examination. It is suggested that the student familiarize himself particularly with the physiology of the eye.

70. Purpose.—The purpose in the preparation of the following part of the manual is primarily to enable the officers to conduct the required examination of Air Corps personnel in a thorough manner and to be able to interpret intelligently the findings of such examinations when he is assigned to duty as flight surgeon. The flight surgeon's responsibility does not cease with routine, original, annual, and semiannual examinations of flying personnel under his care. While he is not expected to become an ophthalmologist (nor by any means will his practice be limited to ophthalmology) he should be able to arrive at an intelligent conclusion regarding the diagnosis of an ocular defect, disease, or injury, and within limitations, to treat such conditions where treatment is indicated. In some instances he may be able to detect an abnormality in its incipiency and by proper measures prevent its development to the extent that the services of a capable pilot are lost. He should remember that he is the "engineering officer" of flying personnel and is as much concerned with "maintenance" as with "selection" of the aviator.

SECTION XIII

VISUAL ACUITY

71. Physiological and psychological factors concerned.—It should be remembered that in asking an individual to read certain test letters on a chart some distance away there are various phychological as well as physiological factors that enter into the examination These are the power of attention, the willingness and ability of the examinee to exert an effort to cooperate, and the power of concentration. There is another factor which, in some instances, may affect the findings obtained, namely, the ability to accurately and precisely control the extrinsic ocular muscles so that the retinal image of the test letters falls exactly upon the fovea, the most sensitive portion of the retina when the definition of form is concerned. Accuracy of fixation is a factor that should be given consideration, particularly in the examination of children.

72. Formation of retinal image.—Before going further into the determination of visual acuity or the appreciation of form, optics may be reviewed to the extent of how an image is formed upon the retina. Consider first a single point seen in the distance, or at infinity; from this point, which may be lighter or darker than its surroundings, rays of light radiate in every direction until interrupted or interfered with in some manner. Of these rays of light there will be a certain number, forming a cone, that will strike the cornea of the eye of the observer. Of the cone of rays of light striking the cornea there will be a certain number of rays that will pass through the pupil, and of these there will be one ray, the axial ray, that will pass through the optical center (nodal point) of the dioptric system of the eye. This ray will not be refracted and eventually will strike the retina at a point where one cone will be stimulated. If the eye be emmetropic, all other rays of light emanating from the point and passing through the pupil will be refracted and will converge upon the point on the retina as stimulated by the axial ray, and the result will be the stimulation of a single cone on the retina. Con-

sider a line as being made up of a series of points immediately adjacent to one another, and follow the formation of a retinal image as by points forming the line. The end result will be the formation of an inverted retinal image greatly reduced in size, of the line being observed. The observation of two lines crossing one another explains the retinal picture in two dimensions.

73. Resolving power of eye.—In determining visual acuity the visual angle is utilized, and this angle is the guide by which test objects have been constructed. By the visual angle is meant the minimal angle formed by the intersection of the two (axial) rays crossing at the nodal point of the eye when two points are seen as separate and distinct points. It is thought that in order to distinguish two points as separate and distinct points, separate cones of the retina must be stimulated and there must exist at least one unstimulated. It is believed that in order to perceive two points as separate and distinct points, the angle formed by the crossing of the two axial rays must be not less than 1 minute, and it is upon this assumption that the Snellen test types are designed. More recently it has been determined that the minimal angle is considerably less, probably around 50 seconds. "The discrimination of two points as separate has been sometimes spoken of as the optical resolving power of the eye" (Adler). There are two other factors which may influence the "visual angle" even in emmetropic eyes, these being aberrations, spherical and chromatic, and irradiation, the latter causing an intensely bright object to appear larger than one of the same size but darker. Quoting Adler directly—

> A good example of this is seen in light from the stars. The visual angle of light coming from the stars is infinitesimal. The rays of light are practically parallel. In spite of this they are visible to us. * * * The factor which determines the visibility of a point of light has nothing to do with the visual angle it subtends, therefore, but depends upon the amount of light energy falling on the visual receptors. The brighter the star the larger it appears.

74. Acuity of retina.—Furthermore, various portions of the retina differ as to degree of sensitivity in perception of form, or acuity, the most acute area being the region of the fovea, and visual acuity rapidly diminishes as the retinal image approaches the periphery of the retina. This is considered as being due to two factors, that the macular area is made up of cones, packed very closely together as it were; and that each of these cones has its own fiber leading back to the brain. In the periphery of the retina there are both rods and cones; these are widely separated, and several of them may be connected with the same fiber so that when one is stimulated the same sensation is produced as when another or several in the

same group are stimulated. A comparison may be made as to the sense of touch upon the skin surface of various parts of the body. For example, one can distinguish two separate points of contact, as pin points, on the finger tip very readily even though they be quite close together, while on the skin of the back the two points must be fairly widely separated in order to be recognized as separate points.

The difference in the ability of varying portions of the retina to recognize detail of form may be easily demonstrated by the use of a perimeter with an ordinary Jaeger near vision card. The acuity will be found to decrease rapidly as the card is moved away from the point of fixation.

75. Alining power of eye.—In the recognition of test letters, such as are used with the Snellen test charts, there is a factor involved in addition to the resolving power of the eye. This may be described as the "alining power of the retina" by which is meant the ability to perceive changes in position or a break in a line. "Although the minimum angle which the eye can resolve is nearly 60 seconds of arc, the alining power of the eye is much more sensitive than this. It is probably the most acute of the human senses. The precision of the eye in adjusting a mark on a vernier scale is extraordinarily deli cate. Under the best conditions a skilled observer will make readings on the scale with an average error of not more than 3 seconds of arc. Thus, the alining power can be 20 times as delicate as the resolving power" (Adler).

76. Conditions that interfere with normal visual acuity.—In the testing of visual acuity (central or foveal) there are some factors to be considered as influencing the findings. These are, in probable order of importance:

a. Errors of refraction or ametropia, in all its varieties, in which the retina is "out of focus" with the dioptric system of the eye, and consequently the retinal image appears poorly defined.

b. The size of the pupil. This may have two effects upon the findings. An increase in the diameter of the pupil naturally allows more light to enter the eye, and with low degrees of illumination will improve visual acuity. Still, a dilated pupil permits an intensification of spherical and chromatic aberrations, which do interfere with a retinal image having sharply defined borders. Where an error of refraction exists, a reduction in the diameter of the pupil will result in an improvement in acuity. This can be easily demonstrated. Granted that the individual is emmetropic, or nearly so, render him myopic by placing before his eye a plus sphere lens of 4 diopters and determine his acuity, which will probably be approximately 10/200. Now place a pinhole disc before the lens and the acuity will be markedly improved,

probably to 20/40 or even better. When an individual is moderately myopic his acuity will be improved by a contracted pupil. Consequently an examinee may present altogether different findings as to acuity when examined with a brilliant light before him (causing a contraction of the pupil) and when examined in a dark room with only the test letters illuminated. Cobb has shown that the pupil should be between 1 and 5 millimeters for optimal visual acuity when the test object is under ordinary illumination.

c. The amount of illumination upon the test objects will affect the findings in an estimate of acuity. The effect of irradiation has already been mentioned. Above a certain point of illumination of test objects acuity will become less and below a certain degree of illumination it will decrease also. These are factors that vary with individuals and are problems necessitating further experimentation before definite conclusions may be reached. In the use of the ordinary electrically lighted test cabinets, it is probable that too much illumination is made use of, rather than too little. It has been found that the most acute vision is obtained when the test letters are illuminated by about 9-foot candles. Recent researches have determined that the maximum amount of illumination before reduction in visual acuity (with test objects) is approximately 300-foot candles for normal individuals. This may be considered as the "glare point."

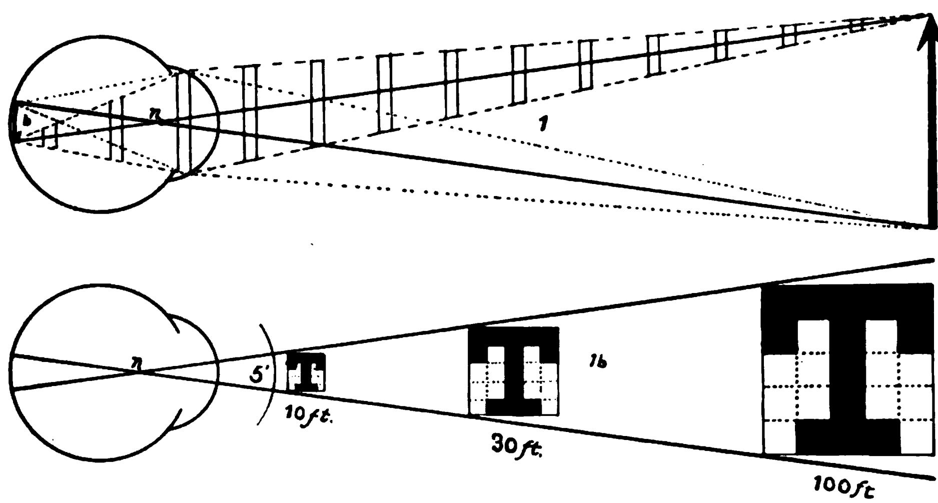
d. Test objects when illuminated by monochromatic light are seen with sharper definition of borders, therefore with increased visual acuity, due to the fact that the factor of chromatic aberration is eliminated.

e. Pathological changes in the eye itself, or optic nerve, chiasm, optic tracts, visual pathways, and higher centers can cause a reduction in visual acuity. For example, choroidoretinitis, retinal hemorrhage, optic atrophy, retrobulbar neuritis, intracranial tumors, etc.

77. Snellen test letters.—The acuity of vision is determined clinically by the use of test letters. These are so designed that each component part, or stroke of the letter, subtends an angle of 1 minute and the letter as a whole subtends an angle of 5 minutes, these dimensions being based on test letters being used at a distance of 20 feet from the examinee. The Snellen test letters, constructed on this principle, are in universal use. Each Snellen test letter is of such shape that it can be placed in a square, which is in turn divided into 25 smaller squares of equal size. Therefore the entire letter subtends an angle of 5 minutes, and each stroke of the letter subtends an angle of 1 minute. It will be noted that on the Snellen test charts there are rows of letters of different sizes, there being usually a row of small-

sized letters of the alphabet, and above or below this row a row of somewhat larger letters, and above still larger, etc. The size of the letters in the different rows is determined as follows: For the smaller row each individual letter subtends an angle of 5 minutes at 10 feet, or approximately 3 meters' distance; in the next row, above or below as the case may be, each letter subtends an angle of 5 minutes at 15 feet; the next, 20 feet, and so on. If an individual being examined, seated 20 feet away from the test types, is able to read readily the row of letters, each of which subtends an angle of 5 minutes at this distance, his vision is recorded as being 20/20, the numerator being the distance from the examinee to the test charts, and the denominator being the size of the letters in the row which is read. If at 20 feet he can read the letters in the row, each of which subtends an angle of 5 minutes at 15 feet, his vision is recorded as being 20/15. Thus we have the findings 20/20, 20/30, 20/40, and so on. The acuity of each eye is tested separately; the eye not being tested is screened by an opaque card or disc. Where an examinee can read all of the 20/30 row of letters, and only three of the letters in the 20/20 row, his vision is recorded as 20/30 plus 3 for the eye being tested.

78. Metric system.—Some examiners use the metric system. In such instances the acuity is recorded as being 6/6, 6/12, etc. These



1. Axial rays from extreme points of object (*a*) passing, unrefracted, through nodal point (*n*), forming inverted image (*b*) upon retina. Associated rays from extreme points of object are divergent and refracted upon entering eye and come to focus on axial rays at retina.

1*b*. Axial rays forming angle of 5 minutes. Test letters are constructed under this angle. Distance from eye determines size of letters.

FIGURE 6.—Diagrammatic illustration of visual angle and method of constructing visual test letters.

fractions may be reduced, and an acuity of 6/6 (20/20) may be recorded as 1; an acuity of 6/12 (20/40) being recorded as 1/2 or 0.5. But a visual acuity of 0.5 does not mean that the examinee has only one-half normal vision from a practical viewpoint. These "fractions" do not signify a percentage of "vision" in that form, being strictly empirical units.

In explanation of repeated references to the use of Snellen test charts at a distance of 20 feet (6 meters), it may be said that this distance is chosen as a mean because at this distance, or distances greater than 20 feet, accommodation plays a very insignificant part in visual acuity of the emmetropic eye. At any distance less than 20 feet accommodation is brought into play, particularly at near distances. Hence, 20 feet is selected as being the minimum as far as convenience and accommodation are concerned. As a matter of fact, the emmetropic eye must accommodate to a certain extent at this distance, presumably one-sixth of a diopter, this strength of lens having a focal distance of 6 meters. The use of a mirror at 10 feet distance with reverse Snellen charts alongside or above the examinee (the mirror may be used at any distance, provided the distance from the chart to the mirror plus the distance from the mirror to examinee is exactly 20 feet) is a great convenience, but care must be taken that the mirror is silvered on the front surface in order that accurate findings are obtained. Otherwise the two reflecting surfaces may cause a blurring of the reflected letters.

79. Readability of various letters.—It is to be remembered that all letters of the alphabet do not possess the same "readability." For example, consider the capital letter "L," which in block form represents a right angle, the apex of which is down and at the left. If visual acuity is defective to such an extent that the outline of the two strokes of the letter is blurred, the letter may be still recognized by the fact that a right angle is formed. The letter "A" may be recognized as A when acuity is below normal because it is the only letter which is characterized by an acute angle apex up, and the examinee may be unable to distinguish the cross bar. The same conditions apply to the letters "T," "V," and even "F"; the latter may be recognized as a right angle apex up and to the left, and the cross bar of the upward stroke not seen. Sheard has concluded after extensive investigation that the letter "B" is the most difficult to distinguish and has prepared a table of comparison of the letters of the alphabet, as follows, using the letter "B" as the unit of measurement 1.00.

L	0.71	C	0.79
T	0.74	O	0.80
V	0.78	Y	0.81

P	0.81	R	0.88
F	0.81	S	0.89
D	0.82	G	0.92
Z	0.84	H	0.92
N	0.85	B	1.00
E	0.85		

The usual Snellen test charts are so arranged that in each row of letters there are an equal number of those that are distinguished readily and those that are more difficult to recognize.

Theoretically, the Snellen test types at 20 feet (6 meters) leave much to be desired as an accurate test of visual acuity, but from a practical viewpoint in conducting a clinical examination they have proven satisfactory. While 20/20 (6/6 or 1) may not be the maximum acuity for the optically normal eye, it serves as a working basis. As a matter of fact, there are many instances of an acuity of 20/15 and better, without hesitation, encountered. Evidence seems to indicate that actually an acuity of 20/15 or better is much more near the normal standard. The examiner should consider a defect in visual acuity as a symptom rather than a disease entity.

In the examination of Air Corps personnel, the examiner should have accessible as great a variety of rows of test types as possible, particularly of the 20/20 size, as the probability of memorizing a row of letters, in many instances seen repeatedly on different occasions by the examinee, is not infrequently encountered. It is suggested that where several rows of the 20/20 types are on hand, one or more be kept in reserve for use in questionable cases. In addition, all letters except one at a time may be screened, which may elicit the fact that an examinee is repeating the letters in sequence from memory when he is permitted to see the entire row at once. If such is the case he will show some confusion where only one letter is exposed and all others screened.

Section XIV

DEPTH PERCEPTION

80. General.—By depth perception is meant the ability to judge distance, or the power to appreciate the third dimension. It is this power that materially aids in rendering an individual capable of correctly orientating himself in relation to surrounding objects. It can be appreciated readily that this is an extremely important factor in aviation. It is this factor that enables the pilot to level off his airplane at the proper distance from the ground in landing, to take off with a safe margin over obstacles, to be proficient in gunnery, and maintain his position in formation flights.

81. Basic and adjunctive factors.—*a. Basic.*—The factors composing the basic group constitute a part of the physical functions of the individual; they are constant, and when considered together may be termed his "inherent ability" to judge distance.

These factors consist of—

(1) Physiological diplopia.

(2) Accommodation.

(3) Convergence.

(4) Binocular parallax.

b. Adjunctive.—The factors composing the adjunctive group may function independent of the individual; they are inconstant, and are common to all persons. They may be termed as factors which assist or enhance the basic group.

These factors consist of—

(1) Size of retinal image.

(2) Motion parallax (movements of head or object).

(3) Terrestrial association.

(*a*) Linear perspective.

(*b*) Overlapping of contours.

(*c*) Light, reflections, and shadows.

(4) Aerial perspective, that is, the changes with respect to color, brightness, and contrast which different objects undergo on account of variation in the clarity of the intervening atmosphere.

82. Monocular and binocular factors.—*a.* Some of the factors operating to constitute depth perception are common to monocular and binocular single vision alike, while others pertain to binocular single vision only.

b. Factors common to monocular and binocular single vision are—

(1) Size of retinal image.

(2) Accommodation.

(3) Motion parallax.

(4) Terrestrial association.

(5) Aerial perspective.

c. Factors which operate with binocular single vision only are—

(1) Physiological diplopia.

(2) Binocular parallax.

(3) Convergence.

d. In employing a test for the purpose of determining an individual's ability to judge distances, it is necessary to utilize only those factors which operate to make for an individual difference in ability; that is, it is necessary to measure an individual's inherent or acquired ability.

In order to do this, the method employed must eliminate all external assistance that experience has taught us to employ. For instance, motion parallax is produced either by movement of the observer or by objects within his field of vision. For that reason it may be considered as an artificial factor employed to enhance the already existing facility. It should, therefore, be eliminated as a factor not related either to inherent or acquired ability.

Factors external to ourselves which assist all of us equally, such as terrestrial association and aerial perspective, should be eliminated for the same reason.

Factors which normally operate only at distances of less than 6 meters, such as accommodation, do not need to be considered when examining prospective aviators. Fliers are not, as a rule, called upon to form judgments at a distance of less than 6 meters.

e. When all external factors and those operating at a distance of less than 6 meters are eliminated, there remains to be considered—

(1) Size of the retinal image.

(2) Physiological diplopia.

(3) Binocular parallax.

(4) Convergence.

83. Size of retinal image.—As the size of the retinal image operates with monocular as with binocular single vision, the relative value of this factor can be obtained with the same testing apparatus by examining first both eyes and then one eye, the other being covered. With the test described herein it has been demonstrated that the ability to judge distances is many times more accurate with binocular single vision than with monocular vision.

In monocular vision, there are eliminated the binocular parallax, convergence, and physiological diplopia. Therefore, judgment must depend upon the size of the retinal image alone.

Since judgment of distance is many times less accurate when the decision depends upon the size of the retinal image alone it follows that the important factors to be considered are physiological diplopia, binocular parallax, and convergence.

84. Physiological diplopia.—The faculty of recognizing differences in distance between objects, which are located in space within our visual fields, is founded upon physiological diplopia, although we do not recognize it as diplopia.

When the eyes fix an object (binocular fixation), the image of that object falls upon the maculae of both retinae. This image is projected outward and we see the object at the point where the visual lines cross, which is the place where the object is actually located. The image of another object within the field of vision, at a greater or lesser distance than the object fixed, falls upon the retinae at points outside of the maculae.

If the second image falls upon the nasal side of the macula of the right eye, it is projected to the temporal field and the object is located to the right of the point actually occupied by the real object, and at a distance equal to the distance between its point of contact on the retina and the macula. If the image falls upon the temporal side of the macula, it is projected to the nasal field and is located in the same manner. The same applies to the left eye. These two images are not focused by the cerebral fusion center and diplopia occurs.

If the image falls upon symmetrical points of the retinae, that is, exact points on the nasal side of one and the temporal side of the other, the images are fused and are projected to the same point in space and diplopia does not occur. Two objects are located in the field of vision and but two objects are seen. However, if the image of the second object falls upon different points of the nasal and temporal portions of the retinae, the two images are not fused and two objects will be seen. The image or images of the second object are not to be confused with the object fixed. The object fixed appears as one and in its proper position.

Figure 7 ① illustrates two objects (*a*) and (*b*) located at different distances in space but within the visual field. The eyes have fixed (*a*), the far object. The image of (*a*) falls upon the macula of both eyes, and appears as one object at the place it actually occupies. The image (*b*), the near object, falls upon the temporal side of the macula of both eyes at (*t*, *t*). Therefore, the image (*b*) seen by the right eye is projected to the left at (b') and the same image seen by the left eye is projected to the right at (b''), giving rise thereby to bilateral crossed diplopia.

In figure 7 ② the eyes have fixed (*a*), the near object. The image of (*b*), the far object, falls upon the nasal side of the macula of both eyes at (*n*, *n*). The image of (*b*) seen by the right eye is projected to the right at (b''), and the same image seen by the left eye

is projected to the left at (b') giving rise thereby to bilateral homonymous diplopia.

Therefore objects located nearer than the object fixed give rise to crossed diplopia, and those more remote than the object fixed give rise to homonymous diplopia. It is because of this homonymous and crossed diplopia that we receive the impression that objects are nearer or farther away in relation to other objects.

In figure 7 ③ the objects (a) and (b) are located in space in positions similar to those occupied by the objects in the Howard-Dolman testing apparatus. The eyes have fixed the near object (a). It will be noted that the image of the far object (b), falls upon the temporal side of the macula of the right eye and upon the nasal side of the left eye, but at a greater distance from the macula of the left eye than the right. These points not being identical, the images are therefore not used but are projected into space as two objects (b') and (b'').

85. Binocular Parallax.—While we perceive, through physiological diplopia, the existence of difference in distance between objects, the binocular parallax augments this perception by giving rise to the impression of relief and solidity.

When we fix an object the right and left eye obtain somewhat different views of that object. The right eye sees a little farther around the object to the right, and the left a little farther around to the left.

This gives rise to two retinal images which are not exactly alike. When these images are fused the disparity is responded to by perception of relief and solidity.

When we perceive a difference in distance between objects our conception of the amount of difference may be accurate or it may be decidedly inaccurate. It is, therefore, desirable to determine the degree of acuracy and this is accomplished by utilizing the binocular parallactic angle.

Figure 8 ① is a representation of two objects (o) and (o') located at unequal distances from the eyes (a) and (b). The two distances may be represented by two imaginary lines, one from (o), the near object, and the other from (o'), the far object, to a point midway between the two eyes, that is, an imaginary Cyclopean eye (an eye occupying the center of the forehead).

These differences may be compared with less difficulty by using a more diagrammatic illustration. Let us therefore consider one eye (b) and the two objects (O) and (O') in a straight line as illustrated in figure 8 ②.

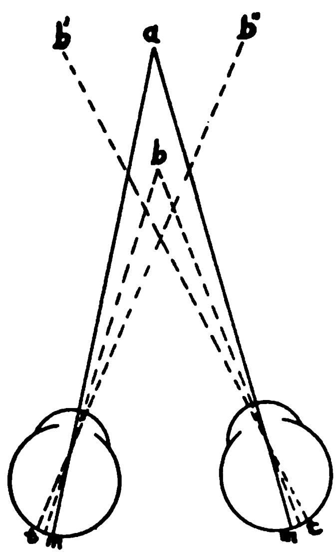
86. Adjunctive group of factors.—The adjunctive factors, with the exception of motion parallax, exist and operate independent of

the individual, but they are probably of as much value in judging distances as are the basic factors.

We are primarily equipped with the essentials for forming judgments and we soon learn, through experience, to utilize all other assistance that comes to hand. However, if these essentials do not function properly, then the value of all external assistance that is available is proportionally reduced because we do not know how to employ it. Because of this it is necessary to determine whether or not the prospective flier possesses all the basic factors of depth perception, and if these factors are functioning properly.

With a normal foundation for judging distances the student soon learns, in his new environment in the air, to utilize all external assistance that is available.

After one becomes experienced in flying he may be deprived of all basic factors, with the exception of the size of the retinal image, and still be able to judge distances sufficiently accurately to fly a ship. This is especially true if he is familiar with the ship, the terrain, etc. This fact is demonstrated with experienced fliers who have lost an eye. At first they experience some difficulty, but this is soon overcome. Their ability to continue flying is due to the fact that flying, landing, etc., have become partially mechanical and subconscious and they have learned from experience how to utilize all external assist-

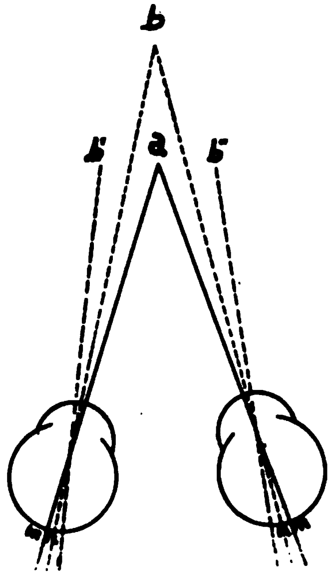


① Eyes fixing far object.

a. Far object. *m–m*. Maculae.
b. Near object. *t–t*. Temporal side of retinae.

Eyes are fixing far object *a*. Image falls upon maculae at *m–m*. Image of *b*, near object, falls upon temporal side of maculae at *t–t* and is projected to *b'* with right eye and to *b''* with left eye, inducing thereby increased diplopia.

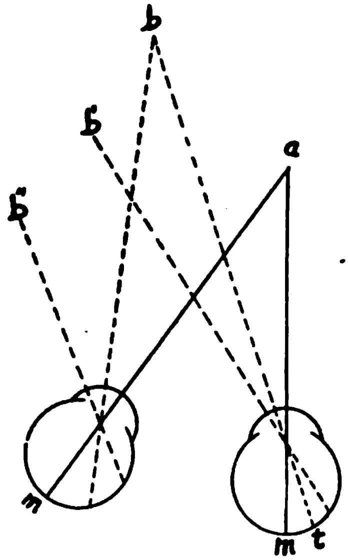
FIGURE 7.—Physiological diplopia.



② Eyes fixing near object.

a. Near object.
b. Far object.
m–m. Maculae.
n–n. Nasal side of maculae.

Eyes are fixing near object *a*. Image falls upon maculae at *m–m*. Image of *b*, far object, falls upon nasal side of maculae at *n–n* and is projected to *b''* with right eye and to *b'* with left eye, inducing thereby homonymous diplopia.



③ Objects arranged similar to those in testing apparatus.

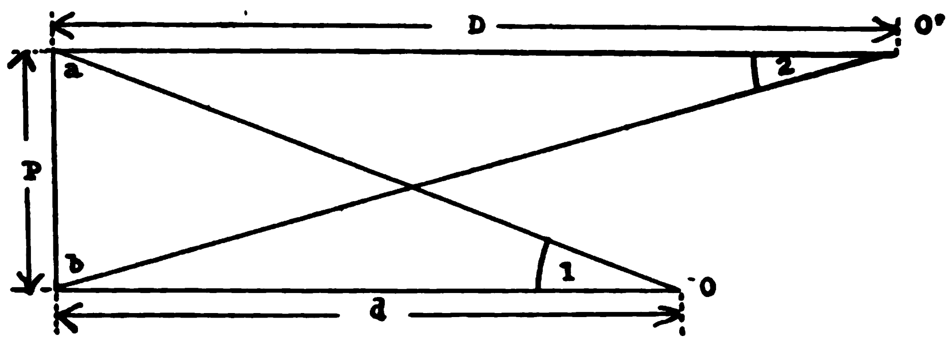
a. Near rod.
b. Far rod.
m–m. Maculae.
t. Temporal side of retina.
n. Nasal side of retina.

Eyes have fixed near rod *a*. Image falls upon maculae at *m–m*. Image of far rod *b* falls upon temporal side of right macula and upon nasal side of left, but image falls upon retina of left eye at greater distance from macula than in right eye. Therefore image of *b* is projected to *b'* with right eye and to *b''* with left, inducing thereby homonymous diplopia with left eye and crossed diplopia with right eye.

FIGURE 7.—Physiological diplopia—Continued.

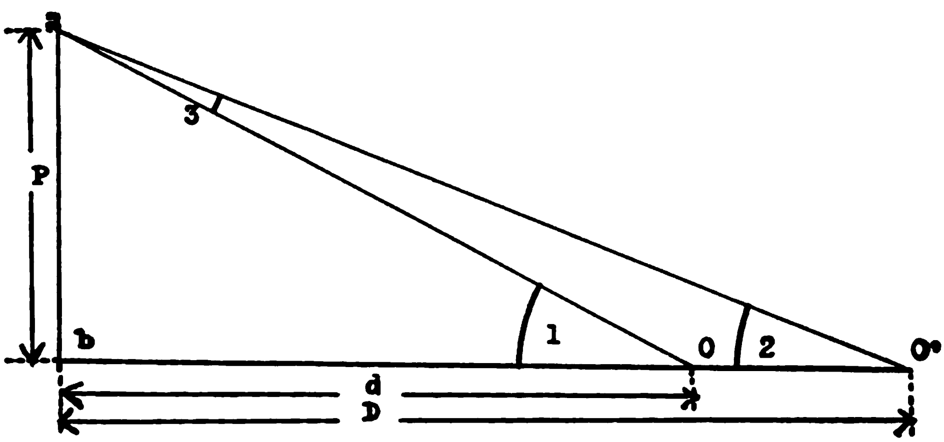
ance to the utmost. However, when these individuals are deprived of all external assistance, and their judgment must depend upon the size of the retinal image alone, as with the testing apparatus, they are many times less accurate than when both eyes are functioning.

87. Measuring parallactic angle.—The Howard-Dolman apparatus employed to measure the parallactic angle is designed to utilize only those factors belonging to the basic group. All external factors



①

d Distance to near object *O*.
P Interpupillary distance *a–b*.
D Distance to far object *O'*.
D minus *d*=difference in distance, or depth difference.
Angle 1 minus angle 2 equals angle of binocular parallactic angle.



②

P Interpupillary distance *a–b*.
d Shorter distance *b–O*.
D Longer distance *b–O'*.
D minus *d*=depth difference.

Let angle 1 equal *aOb*, angle of convergence upon near object, angle 2 equal *aO'b*, angle of convergence upon far object, and angle 3 equal angle *OaO'*. Then angle 1 minus angle 2 equals angle 3, which is the binocular parallactic angle represented by depth difference *D–d*.

Figure 8.—Binocular parallax.

which usually operate to assist in judging distances are eliminated. The examinee is given two objects at unequal distances from him. His physiological diplopia, binocular parallax, and convergence tell him that a depth difference exists between the two objects. It is his task to eliminate this difference, that is, to place the objects at equal distances from him. The accuracy with which he accomplishes this determines his inherent degree of ability to judge distances.

The testing apparatus consists of two upright rods, 64 millimeters apart, laterally, viewed through an aperture in a screen at a distance of 6 meters. All that is visible to the examinee is an illuminated white background crossed vertically by two black rods. One rod is stationary and the other can be moved backward and forward in a groove along the margin of a millimeter scale by means of cords. The examinee endeavors to place the adjustable rod beside the stationary one so that both are at equal distances from him. When the rod is accurately placed the reading on the millimeter scale is zero, and the parallactic angle and physiological diplopia cease to exist.

The abolition of diplopia and the parallactic angle can be demonstrated with the figures 7 ③ and 8 ②. If the object (*b*), figure 7 ③, is placed at the same distance from the eyes as (*a*), then the image of (*b*) will fall upon symmetrical points of the retinae, become fused, and be projected to the left of (*b*), as a single object. In figure 8 ②, if (*O′*) the far object, is placed beside (*O*) the near object, the binocular parallactic angle (3) will be eliminated.

The testing apparatus is so constructed that the size of the binocular angle will equal 10.3 seconds when the interpupillary distance is 64 millimeters, the stationary rod is located at 6 meters distance and a depth difference of 30 millimeters exists between this and the adjustable rod.

Among Americans, interpupillary distances range from 58 to 74 millimeters with an average of 64. In conducting tests it is impracticable to compute the size of the parallactic angle of every individual whose interpupillary distance is greater or less than 64. Therefore, a depth difference of 30 millimeters is taken as the outside limit and those who persistently exceed this limit are considered as defective in judging distances.

It has been demonstrated that an individual who persistently projects the adjustable rod more than 30 millimeters from zero, and possesses an ocular defect, experiences great difficulty in learning to fly.

88. Etiology of defective depth perception.—*a. Occurrence of defective perception.*—Ninety-nine and one-half percent of persons who are free from nervous, ocular, and general defects exhibit a per-

sistent parallactic angle average 10.3 seconds or less, that is, they will persistently project the adjustable rod an average of not more than 30 millimeters from zero. The remaining one-half percent of this class of individuals will project the adjustable rod more than 30 millimeters from zero for a large number of trials, but will eventually project it less than 30. Just why this occurs has not been definitely determined, but the cause seems to point to nervousness, poor comprehension, and particularly to carelessness in performing the test.

These men usually project the rod between 30 and 50 millimeters from zero. If they persist in this indefinitely they are considered as defective in judgment, but if they correct this error, after two or three series of trials, they are considered normal. Observation has taught us that these men experience no difficulty in flying, that is, insofar as judgment is concerned. Furthermore, practice on the testing apparatus will not reduce the average error when an ocular defect exists.

b. Known factors operating for poor depth perception.

(1) Inequality of vision.

(2) Refractive errors resulting in accumulative ocular fatigue and manifested by—

(*a*) Accommodative asthenopia.

(*b*) Heterophoria.

(*c*) Insufficiency of convergence.

All individuals, with the exception of the small number mentioned above, who are inaccurate in their judgment of distances are found to have one or more of the above defects. These individuals will project the adjustable rod 75 millimeters from zero in one direction, in the next trial will project it 150 millimeters in the opposite direction, and in still another trial may place it at zero. In other words, they have no conception of the relative or actual positions of the rods.

However, it must be remembered that some individuals may have all the defects enumerated above, with the exception of inequality of vision and still possess a very accurate estimation of distances, but in general, it may be stated that when any of the defects mentioned are severe enough to cause symptoms, for example, muscular fatigue, blurring of vision, diplopia, etc., judgment of distances is inaccurate, and the degree of inaccuracy is in proportion to the degree of symptoms manifested.

c. Inequality of vision or anisometropia.—Given a case with a visual acuity of 20/20 in one eye and 20/50 in the other, and assuming that there is no strain of accommodation in the defective eye,

the defective judgment is due, under these conditions, to an inability to utilize fully the assistance afforded by physiological diplopia and binocular parallax. The cerebral interpretation of this diplopia

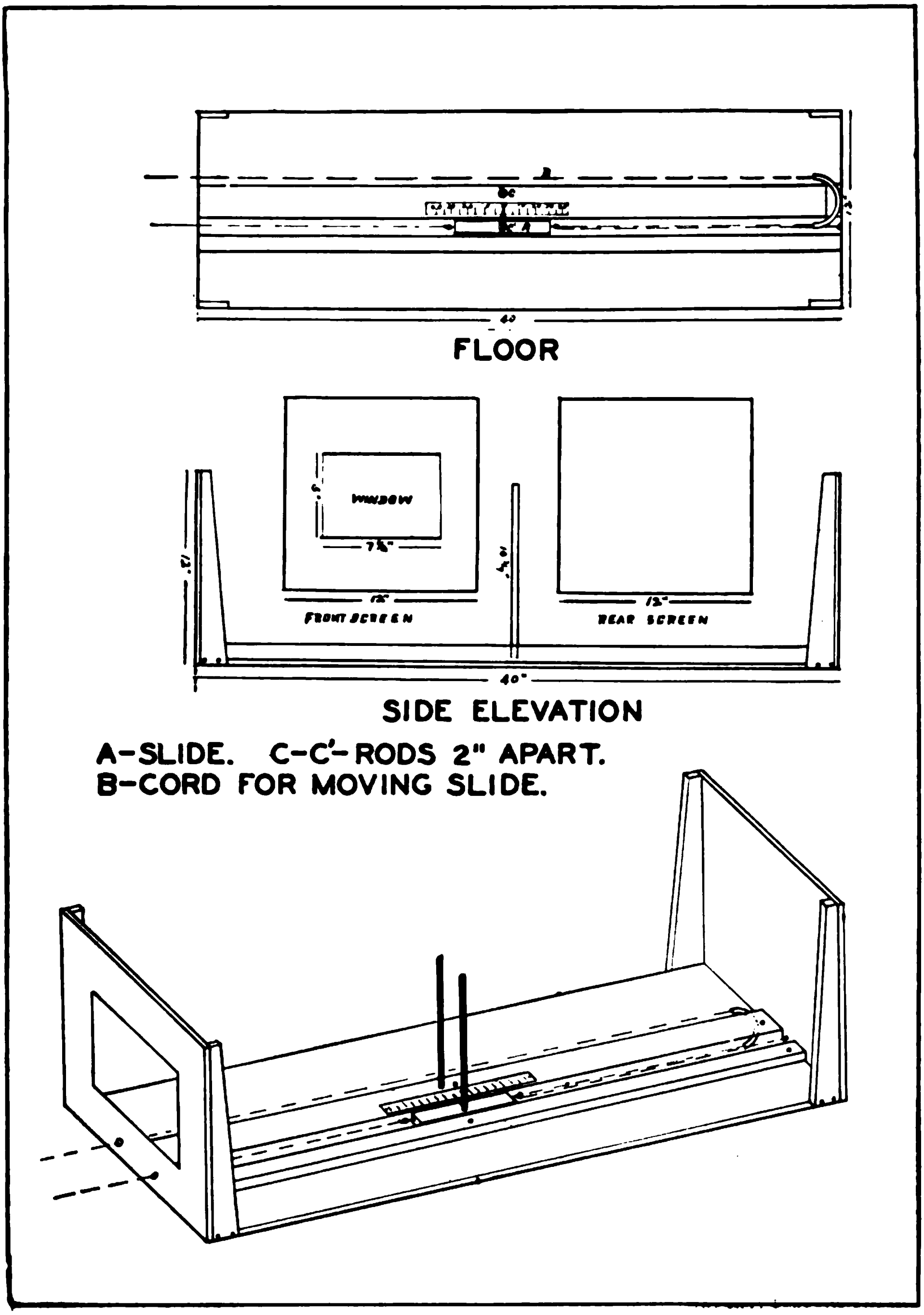


FIGURE 9.—Depth perception apparatus.

into distances is partially lost because of the diminished vision, also the impression of relief is not as marked as normal. Therefore the individual is utilizing monocular judgment in his estimation to a greater or less extent and the greater the reduction in vision the nearer will binocular approach monocular vision.

d. Hyperopic refractive errors.—The existence of refractive errors creates a defect in the ocular mechanism and when accumulative fatigue ensues as a result of work, nervous strain, infection, etc., it is the existing defective structure that is first to become impaired in function.

When hyperopic refractive errors exist, the individual must at all times accommodate to bring far as well as near objects into focus. Therefore, in order to do this the ciliary muscles must receive a greater amount of enervation than is required by a normal eye, and the increased amount is interpreted into distance by the cerebrum. Consequently the amount of nervous force employed gives rise to the sensation of a proportional amount of distance. Usually this apparent distance is less than that which actually exists.

When the refractive error is equal in both eyes and is fully compensated for by accommodation, the defective judgment resulting therefrom frequently can be corrected. The increase of nervous impulse required to correct the defect is equal in both eyes. If the object upon which the eyes fix appears nearer or at a greater distance than it really is, the other objects or object will be falsely projected in proportion, and the relation between the two will remain unchanged. This type of defect gives rise to faulty landings. The student will persistently level off too high or too low until he has learned to compensate for his error.

When the refractive errors are unequal in the two eyes, for example, one-half of a diopter in one and one diopter in the other, the higher error will require the greater amount of nervous impulse to accommodate. The unequal nervous strain will alter the apparent relative position of objects, and defective and erratic judgment results.

e. Accommodative asthenopia.—When accumulative ocular fatigue is present, there are usually errors in refraction responsible for it. As it is necessary to accommodate constantly for distant objects, the eyes become tired as a result of the nervous and physical strain, accommodation relaxes, and objects are seen out of focus. Because of the indistinct vision an accurate estimation of distance is impossible. This condition is particularly noticeable in some individuals who are undergoing flying training. One day they can judge dis-

tances very accurately and experience no difficulty in landing their ships, while on the following day they cannot level off and land consistently or accurately. These cases have latent hyperopic errors, and because of the mental and physical strain incident to training, their accommodative powers become reduced and objects are not brought into focus. The wearing of correcting lenses usually improves the faulty judgment.

f. Heterophoria.—Heterophoria may be considered as fatigue of one or more of the extrinsic ocular muscles due to refractive errors, to a deficiency in the normal amount of enervation from some cause, or to an actual defect in the muscle structure itself. In order to fix both eyes upon an object the defective muscle must receive a greater amount of enervation than its fellows. This increased amount of enervation is interpreted into distance by the cerebrum just as it is in refractive errors, therefore the relative position of objects is inaccurately judged. If the defective muscle becomes sufficiently fatigued, or the required amount of nervous impulse cannot be supplied, the visual line of the eye concerned will deviate and objects will become blurred or pathological diplopia will ensue. When diplopia occurs all objects within the field of vision appear double, the true objects appearing more distinct than the false objects.

g. Insufficiency of convergence.—Convergence must occur at all times in order to fix both eyes upon an object, no matter how remote, but the degrees of convergence required for distant objects are necessarily less than those for near objects. When the eyes become fatigued, convergence relaxes and objects are blurred or pathological diplopia results. This condition is usually associated with refractive errors, as is the condition of heterophoria.

h. Myopic refractive errors.—Myopic errors have little or no effect upon depth perception, until the errors are sufficient to cause indistinct images and a strain upon convergence. When the errors are sufficient to cause these symptoms, depth perception becomes defective as in insufficiency of convergence and inequality of vision.

89. Summary.—Accurate judgment of distances is important to the aviator because, if this sense or function is impaired, it is impossible for him to learn to fly an airplane safely unless he is given an enormous amount of flying training. He may under these conditions become sufficiently proficient to fly with comparative safety, but he will never attain even an average degree of proficiency.

Inherent depth perception for objects located in infinity is dependent upon physiological diplopia and augmenting this diplopia are binocular parallax, size of the retinal image, and convergence.

Physiological diplopia is interpreted into distance by the cerebrum and the binocular parallax gives rise to the impression of relief and solidity.

An adjunctive group of factors assist inherent depth perception. These factors are common to all persons; they are inconstant but they play a very important part in accurate judgment.

The degree of accuracy of judgment is determined by the size of the binocular parallactic angle. The testing apparatus is so constructed that with an interpupillary distance of 64 millimeters, the stationary rod at 6 meters distance, and a depth difference between this and the adjustable rod of 30 millimeters, the binocular parallactic angle thus formed subtends an angle of 10.3 seconds.

In determining the degree of accuracy in judging distances only the basic group of factors is considered, because if these are not functioning properly the adjunctive factors cannot be utilized fully. An experienced flier who has been deprived of some of the basic factors may be able to fly a ship with reasonable safety because he has learned from his flying experience to utilize to a marked degree the adjunctive factors. However, he is not as safe or reliable as the normal person.

Ninety-nine and one-half percent of persons who are inaccurate in judgment have a defective ocular mechanism. These defects may be reduction of vision in one or both eyes or refractive errors resulting in ocular fatigue and manifested by accommodative asthenopia, heterophoria, or insufficiency of convergence.

A persistent parallactic angle of more than 10.3 seconds, that is, a depth difference of more than 30 millimeters, is considered as defective provided an ocular defect is present.

Any hyperopic error in refraction may cause inaccurate judgment. Myopic errors have little effect upon judgment unless the error is sufficient to cause diminished acuity of vision and insufficiency of convergence.

If in the first series of trials the candidate makes an average error of over 30 millimeters, for example, between 30 and 50, and no ocular or general physical defect can be found to account for it, it is advisable to recheck him every day for at least 3 days. Invariably these candidates will eventually attain an average error of 30 millimeters or less. Experience has taught us that these individuals experience no difficulty in flying, insofar as judgment of distances is concerned.

SECTION XV

OCULAR MOVEMENTS

90. Monocular and binocular projection.—*a. General.*—After the estimation of visual acuity and ability to judge differences in depth or distance, there is to be determined whether or not there exists any abnormality in the motility of the eye. Under this heading there are to be considered, in the examination of flying personnel, the Maddox rod screen test at 6 meters, the power of divergence, power of convergence, and associated parallel movements. Before taking these up in order, it is worth while to discuss briefly orientation of objects, binocular vision, the field of binocular fixation, the action of the extrinsic ocular muscles, defects in ocular movements, and the methods used in arriving at a conclusion in this phase of the examination.

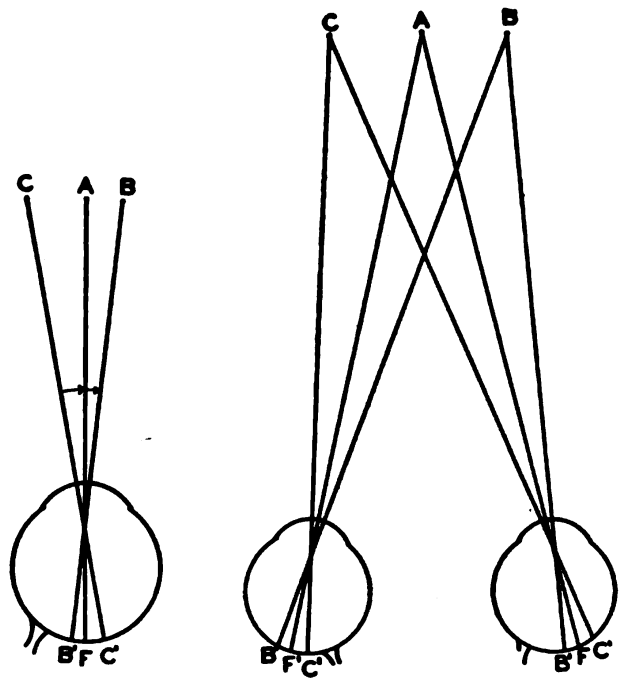
b. Monocular vision.—First, consider monocular vision, using the right eye alone. When a point (A) (fig. 10 ①) upon the horizon or at

infinity fixed upon, the extrinsic ocular muscles of the eye are brought into play so that it is rotated to such a position that the retinal image of that point is formed on the fovea of the retina, where it is most clearly defined. Now suppose there is another point (*B*) to the right of point (*A*), or the point of fixation, and it is located 10° to the right of point (*A*). The image of point (*B*) will be formed on the retina 10° away from the fovea on the nasal side of the right eye. If there is a third point (*C*) located 20° to the left of point (*A*) its image will be formed on the temporal side of the right retina 20° away from the fovea. The position of objects in space is determined by their relation to the nodal point of the eye. If an image of an object is formed on the retina a number of degrees away from the fovea, this image will be projected in space the same number of degrees to the opposite side of the point of fixation, that is, if an image is formed on the retina at 10° to the nasal side of the fovea, it will be projected in space 10° from the point of fixation in the temporal field of vision. Or if an image is formed 10° above the fovea the object in space is projected 10° below the point of fixation.

c. Binocular vision.—Now let us suppose both eyes are brought into use, and both eyes are fixed on point (*A*) (fig. 10 ②), point (*B*) (to the right of point (*A*)) will have its image formed at a point 10° medial to the fovea of the right retina, and 10° lateral to the left fovea. Point (*C*) (to the left of point (*A*)) will have its retinal image formed 20° away from the right fovea on the temporal side, and 20° from the left fovea on the nasal side. However, point (*B*) seen with both eyes will be seen as a single point, the images on the right and left retinae being fused into one. The same is true, of course, with point (*C*). When fusion occurs we may conclude that it is because images are formed on the two retinae at corresponding points. The two foveae are corresponding points; 10° to the nasal side of the right fovea and 10° to the temporal side of the left fovea are corresponding points; and so on. However, 10° immediately above the right fovea has a corresponding point 10° above the left fovea. When we fix upon an object in the distance, images of objects to the right and left of the point of fixation will be formed on corresponding points of the retinae and binocular single vision results. Points of the two retinae which are not corresponding are known as disparate points. When retinal images of the same object are formed on disparate points diplopia results.

d. Convergence.—When an object nearer than infinity is the point of fixation there is necessarily a certain amount of convergence, or adduction, accomplished in order that the visual lines (visual line

being a line from point of fixation through nodal point to fovea) intersect at the point of fixation, and the image of this point is formed upon the fovea of each retina.



① Monocular.

A is point of fixation. The image of *B*, to the right of *A*, would fall on the retina at *B'* on the nasal side of the fovea, *F*. The image of *C* would fall on *C'* on the temporal side of the fovea.

② Binocular.

A is point of fixation. The image of *B* would fall on corresponding points on the right and left retinae.

FIGURE 10.—Projection.

91. Field of fixation.—*a. Definition.*—"The field of fixation may be defined as the base of a cone, the apex of which is the center of rotation of the eyeball as the eye is rotated to its extreme limits in all directions, foveal vision at all times marking or defining the base of the cone" (Peter). Thus, foveal or central vision is limited to within the field of fixation, is limited by the possible amount of rotation of the globe about its center. The average field of fixation extends upward 33°, up and in 47°, inward 50°, in and down 47°, downward 57°, downward and outward 47°, and outward 45°. The field of fixation, like the visual field for form, is limited on the medial side by the contour of the nose, so that a proper determination of the maximum degree of adduction of the eye is difficult to determine.

b. Binocular fixation.—The field of binocular fixation may be considered as consisting of the overlapping portions of the right and left fields of fixation. It is only within the binocular field of fixation that binocular single vision is possible, and it is only within this area that the factors which operate with binocular single vision in depth perception (physiological diplopia, binocular parallax, and con-

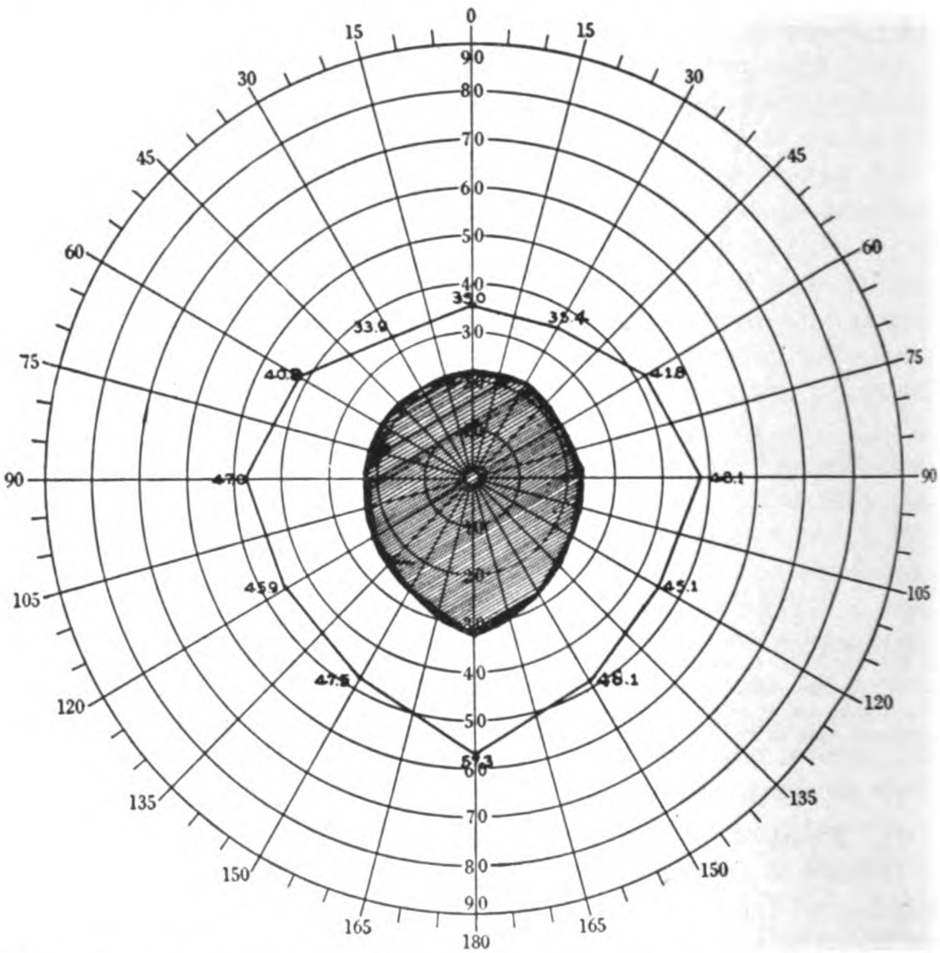


FIGURE 11.—Composite field of binocular vision of 50 men, showing concentric constriction when flying goggle B–6 is worn (outer line normal field; shaded area field with goggle worn).

vergence) can be employed. Therefore accuracy in depth perception is limited to the field of binocular fixation. We may say that the field of binocular fixation is limited by the nasal field of fixation of each eye. This fact should be remembered and given consideration in aviation goggle design.

c. Normal position.—Normally, the eyes are held in their proper position in the orbits by the combined action of the extrinsic ocular muscles and are so acted upon by these muscles that the visual lines are held practically parallel.

d. Diplopia.—While the extrinsic ocular muscles hold the eyes in their proper positions, these muscles in turn are directed to their action by nervous impulses originating in the fusion centers. These fusion centers operate to maintain binocular single vision under all normal conditions. In order to maintain such vision, the lines must be held in their proper relation to each other. When visual lines fail in this respect, diplopia or double vision results.

92. Orthophoria and heterophoria.—When the action of the fusion centers is weakened or abolished, normally balanced eyes will maintain parallel visual lines (orthophoria). If the visual lines deviate from the parallel under these conditions, heterophoria exists, that is, a deviation becoming manifest only when fusion control is weakened or abolished. If the visual lines deviate from the parallel while the fusion centers are presumably functioning, and fixation is maintained with one eye only, heterotropia or squint exists, that is, a manifest or obvious deviation of the visual lines occurring independent of the action of the fusion center. The term heterophoria includes all varieties of latent tendencies to deviation from parallel positions of the visual axes. In heterotropia the deviations are manifest and do not have to be uncovered by weakening the fusion control. The following table of nomenclature is generally accepted:

a. Orthophoria.—Normal binocular balance.

b. Heterophoria.—A latent imbalance, or tendency toward deviation of the two visual lines from parallel. It includes the following:

(1) *Esophoria.*—A latent deviation of the visual lines inward.

(2) *Exophoria.*—A latent deviation of the visual lines outward.

(3) *Hyperphoria.*—A latent deviation of the visual lines of one eye above that of the other. It is designated as right or left.

(4) *Hypophoria.*—A latent deviation of the visual lines of one eye below that of the other. Designated as right or left.

(5) *Double hyperphoria.*—A latent elevation of both visual lines. Also termed anaphoria.

(6) *Double hypophoria.*—A latent lowering of both visual lines. Also termed kataphoria.

(7) *Cyclophoria.*—A latent deviation of the globe about its antero-posterior axis, that is, an intorsion (rotation of the upper portion of the cornea about the antero-posterior axis of the globe nasally or

inward) or an extorsion (outward rotation), necessarily designated as right or left.

c. Heterotropia.—A manifest deviation of the visual lines (as defined previously).

(1) *Esotropia.*—A manifest deviation of the visual lines inward; a convergent squint.

(2) *Exotropia.*—A manifest deviation of the visual lines outward; a divergent squint.

(3) *Hypertropia.*—A manifest deviation of one visual line above the other—right or left.

(4) *Hypotropia.*—A manifest deviation of one visual line below the other—right or left. Also termed catatropia.

(5) *Cyclotropia.*—A manifest deviation about the antero-posterior axis.

d. Other diagnostic terms used in connection with defective ocular movements are:

(1) *Hyperkinesis.*—Excessive action of an individual muscle.

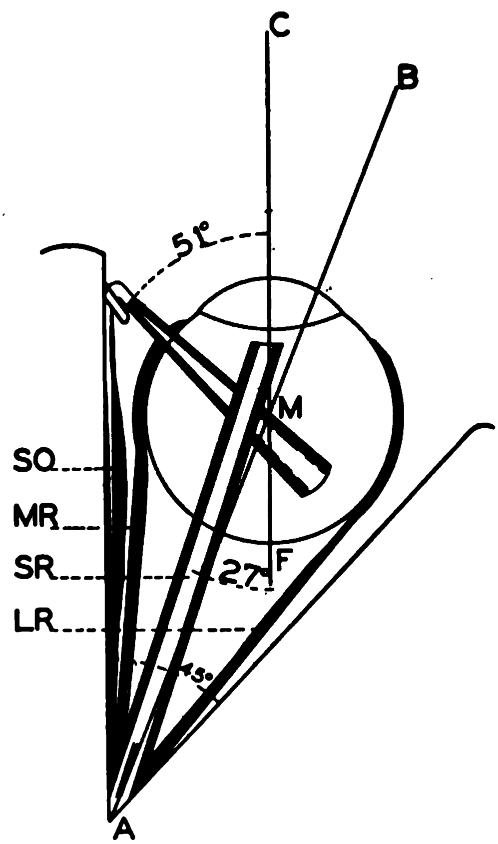
(2) *Hypokinesis.*—Deficient action of an individual muscle.

93. Review of physiology of extrinsic ocular muscles.—*a. Movement of globe.*—The globe is capable of limited movements about the center of rotation, these movements being brought about by contractions of the extrinsic ocular muscles. The center of rotation is located about 10 millimeters in front of the posterior pole and 13½ millimeters behind the anterior pole (Donders). The globe may be rotated about three axes, the horizontal axis (as elevation and depression), the vertical axis (as abduction and adduction) and the antero-posterior axis (intorsion and extorsion).

b. Action of muscles.—Certain of the extrinsic ocular muscles have but one action from the position of "eyes front," these being the external rectus (abduction, external rotation) and internal rectus (adduction, internal rotation). Each other muscle has a primary and subsidiary action. Taking them up in order we find that the vertical recti (superior and inferior) in addition to their vertical action have an adducting or internal rotating effect because of their origins being located more medially than their insertion. In addition each has some effect in rotating the globe about its antero-posterior axis. Because of the forward and medial origin of the obliques and their insertions behind the center of rotation, each is an abductor in addition to its elevating and depressing and torsion actions. The primary and subsidiary actions of the muscles can best be appreciated after a study of diagrams showing their origin and insertions.

Table of primary and subsidiary actions of individual ocular muscles
(Peter)

Muscle	Primary action	Subsidiary action
Internal rectus	Internal rotation	None.
External rectus	External rotation	None.
Superior rectus	Elevation	Internal rotation. Intorsion.
Inferior rectus	Depression	Internal rotation. Extorsion.
Superior oblique	Intorsion	Depression. External rotation.
Inferior oblique	Extorsion	Elevation. External rotation.



AB. Orbital axis.
CF. Optical axis.
M. Center of rotation.

FIGURE 12.—Planes of action of extrinsic ocular muscles. Inferior oblique lies immediately beneath superior oblique, and inferior rectus immediately below superior rectus.

c. Synergists and antagonists.—No movement of the globe is accomplished by the action of an individual muscle alone. Those that aid one another in a movement are called synergists. For every movement made by the globe there is a diametrically opposed movement. The muscles that oppose one another in contraction may be termed antagonists.

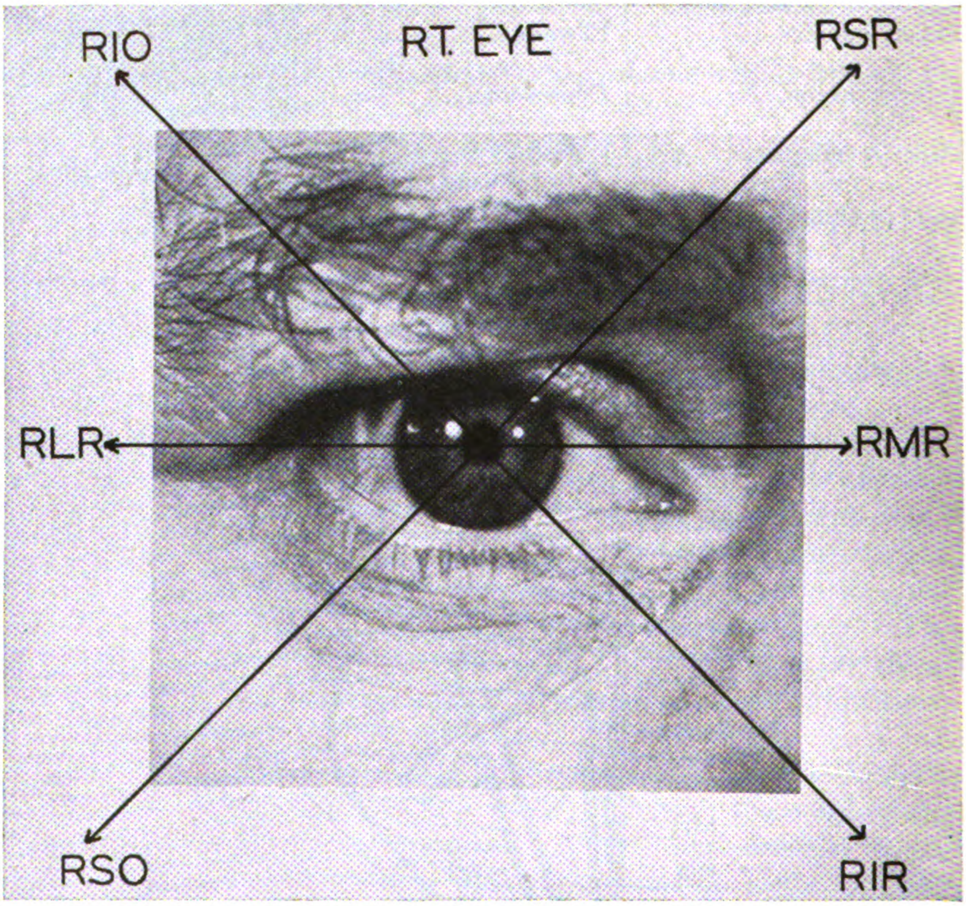


FIGURE 13.—Diagram showing action of individual muscles in the six cardinal directions of gaze from position of "eyes front."

Table of synergists
(Peter)

Muscle	Synergist
Internal rectus	Superior rectus. Inferior rectus.
External rectus	Superior oblique. Inferior oblique.
Superior rectus	Inferior oblique. Internal rectus.
Inferior rectus	Superior oblique. Internal rectus.
Superior oblique	Inferior rectus. External rectus.
Inferior oblique	Superior rectus. External rectus.

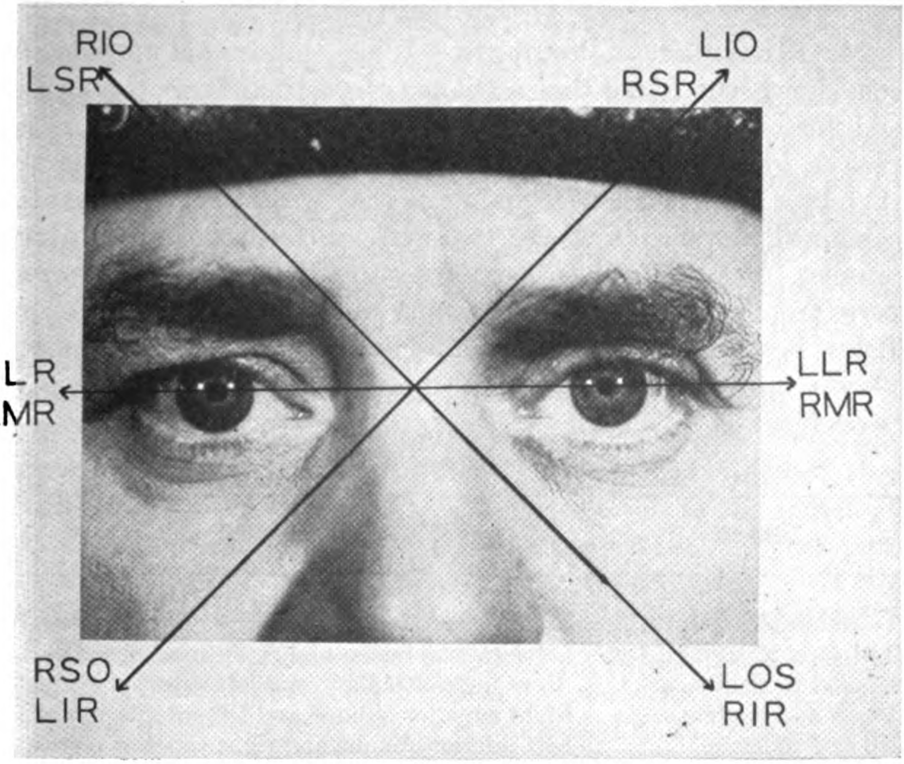


FIGURE 14.—Diagram showing conjugate or yoke action of extrinsic ocular muscles in binocular movements.

Table of direct antagonists
(Peter)

Muscle	Antagonists
Internal rectus	External rectus. Superior oblique. Inferior oblique.
External rectus	Internal rectus. Superior rectus. Inferior rectus.
Superior rectus	Inferior rectus. Superior oblique.
Inferior rectus	Superior rectus. Inferior oblique.
Superior oblique	Inferior oblique. Superior rectus.
Inferior oblique	Superior oblique. Inferior rectus.

94. Binocular movements.—When binocular movements are considered it is found that a change of position from "eyes front" to a different position within the field of binocular fixation is accomplished by the combined action of muscles of each eye. The muscles that by their contraction maintain the two visual lines parallel in combined movements of the two eyes are termed conjugate or yoke muscles. For example, in looking toward the right from the position "eyes front" the right external rectus and left internal rectus contract. Below is a table showing the conjugate or yoke muscles brought into play in movements in the six cardinal directions from the position of "eyes front."

Table of conjugate muscles

Direction	Muscles
To right	Right external rectus and left internal rectus.
To left	Left external rectus and right internal rectus.
Up and to right	Right inferior oblique and left superior rectus.
Down and to right	Right superior oblique and left inferior rectus.
Up and to left	Left inferior oblique and right superior rectus.
Down and to left	Left superior oblique and right inferior rectus.

95. Prisms.—In the recognition of heterophoria and heterotropia the use of prisms is of great value, particularly in arriving at a quanti-

tative diagnosis. Therefore a consideration of the optical properties of prisms is now essential.

A prism may be defined as a portion of a refracting medium bounded by two plane surfaces which are inclined at a finite angle. The two plane surfaces are called faces, the line of their intersection the edge, the angle between the faces the apical angle, and the side opposite this angle the base. If a prism is of a denser medium than that surrounding it (for example, glass in air), a ray of light on entering it will be bent toward the base as it enters the prism, upon passing through the denser medium and reentering the rarer medium, the emergent ray will further be bent toward the base as it leaves the prism. When the ray of light, while passing through a prism, is parallel to the base, it is said to traverse the prism symmetrically and in this case the angles of incidence and emergence are equal. The total amount of deviation between the incident ray and the emergent ray is called the angle of deviation. A ray of light passing through is deviated toward the base, and the image of an object seen through a prism is projected or displaced toward its apex (Duke Elder).

96. Numbering of prisms (Peter).—As to the nomenclature of prisms, three methods have been proposed and used:

a. Numerals indicating angle in degrees formed by the two refracting surfaces or faces.—This method is unsatisfactory inasmuch as the amount of deviation produced varies with the index of refraction of the material as well as the angle of the apex, or in other words depends upon the material from which the prism is made in addition to the angle of the apex. Therefore, it does not express the amount of deviation undergone by a ray of light passing through the prism.

b. The centrad method of Dennett.—The unit, centrad, is designated symbolically by the Greek letter delta inverted (triangle base up). A prism of 1 centrad value will deviate a ray of light 1/100th part of the arc of the radian. The radian of the arc is obtained by measuring off on the circumference of a circle a distance equal to the radius of the arc. A radian equals 57.295°, therefore one centrad, 1/100th part of the radian, is 0.57295°. This unit of measure is constant.

c. *Prentice's method of prism diopter.*—Designated by the Greek letter delta (triangle base downward). A prism of 1 diopter's strength will deviate a ray of light 1 centimeter at 1 meter's distance, or 1 inch at 100 inches' distance. It is purely a tangential measurement. One prism diopter equals 34.37643 minutes. This unit is not constant, that is, a 10-diopter prism does not equal 10 times a 1-diopter prism, but equals 5°42.6355′. The two units of measure, centrad and diopter, are so nearly equal up to 20 that either system may be used with ap-

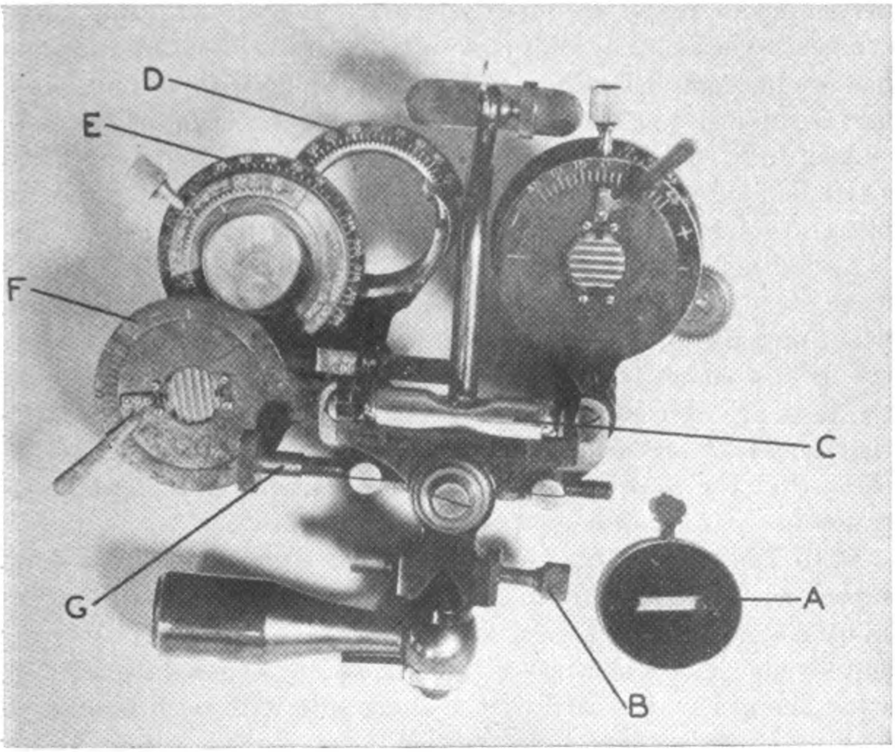
proximately equal accuracy. But beyond 20, while the centrad continues to be uniform the prism diopter loses in value. The prism diopter is the method we shall use in the quantitative determination of heterophoria.

97. Rotary prism.—If two prisms of equal value, for example 10 diopters, are placed together base to apex, one will neutralize the other. If one is rotated against the other until the two bases are together there will be a prism equal in value to the sum of the two, that is, 20 diopters. If the two prisms of equal strength are placed together, one (*a*) base up and the other (*b*) base down and rotate them against one another in opposite directions an equal amount, that is, (*a*) with base up and out at 45°, and (*b*) base down and out at 135°, there will be a prism of a certain value base out only, as the base up and base down effects are neutralized. This illustrates the principle employed in the construction of the Risley rotary prism; the two prisms are rotated in opposite directions by a rack and pinion arrangement so that when properly calibrated any prismatic effect may be obtained from zero to the sum of the two. Further, the base may be placed in any position desired, that is, base up or down, in or out. A rotary prism amounts to a case of simple prisms and, while a great convenience and time saver, is not essential in the determination of heterophoria. The prisms from the trial lens case may be used quite satisfactorily if a rotary prism is not available.

98. Maddox rod.—The Maddox rod is used in the determination of the existence of heterophoria. In its simplest form it is a section of small glass rod, probably 4 or 5 millimeters in diameter, mounted in an opaque black disc which is fitted in a trial lens frame. The type found on the usual phorometer trial frame is multiple, or compound, that is, several rods superimposed with the axes parallel and within the same plane. It is believed that the multiple, or compound, Maddox rod gives sharper definition. The Maddox rod, either single or compound, refracts only in one meridian and that at right angles to its axis. If a small luminous point is seen through a Maddox rod the point appears as a luminous line at right angles to the axis of the rod. When the rod is placed in a horizontal position before the eye, and a luminous point seen through it, the luminous point appears as a vertical line of light. When the Maddox rod is placed before an eye, the retinal image of a luminous point is therefore distorted. If a Maddox rod is placed before the left eye and the right fixed upon a luminous point of light (1-centimeter lamp at distance of 20 feet), the left retinal image of the luminous point is so distorted that it is not recognized as the same object seen with the right eye, fusion control

is greatly weakened or reduced, and the left visual line will follow the lines of least resistance. If a muscular imbalance exists, the eye behind the rod will deviate inward or outward, etc., as the case may be. We may say then that the Maddox rod has the optical effect of converting a point of light into a line of light at right angles to its axis, and has the psychological effect of weakening or abolishing in part, at least. fusion control.

99. Phorometer trial frame.—*a. Description.*—The phorometer trial frame as used routinely in the examination of Air Corps personnel consists of a triple cell trial frame, one cell capable of being rotated, as for cylindrical lenses, a Risley rotary prism, and a compound Maddox rod for each eye. The rotary prisms and the Maddox rods can be swung into place, that is, one each before each triple cell, as desired. The rotary prisms may be adjusted to any position,



A Single Maddox rod.
B Leveling device.
C Bubble.
D Triple cell (one rotary) for trial lenses.
E Risley rotary prism.
F Multiple Maddox rod.
G Adjustment for interpupillary distance.

FIGURE 15.—Phorometer trial frame and single Maddox rod.

base up or down, in or out, as desired, and with it any prismatic effect, from 0 to 30 diopters may be obtained. The Maddox rods may be placed with the axes in any meridian, being capable of being rotated through 180°. The instrument is equipped with a level bubble and leveling device, has an adjustable forehead rest, is adjustable for interpupillary distance, and mounted on a telescoping floor stand or wall bracket.

b. Use.—It is believed advisable that first the student disregard the phorometer trial frame and use only the equipment from the trial lens case in arriving at conclusions regarding heterophoria in order to realize the optical principles involved. Later the phorometer trial frame may be used as a matter of convenience, but as has been stated, it is not essential.

100. Sighting eye.—Before beginning the tests for the detection of heterophoria, it is necessary that the sighting or fixing eye be determined. When an object is fixed it is habitually done with one eye, while the other eye adjusts itself to take up fixation after this act has been accomplished by the former. The eye that sights an object first is referred to as the sighting, fixing, or directing eye.

As a rule, a right-handed person will sight with his right eye, and a left-handed person with his left. However, this rule is not infallible, and too much reliance should not be placed on it.

Assuming that the eye one employs habitually for sighting is the more steady or nondeviating of the two, it is advisable, therefore, when measuring deviations to allow the examinee to sight with the eye he customarily employs for that purpose. When this is observed the tests are carried out with the nonsighting eye, as this is the eye that deviates more readily should any deviation occur. Investigations show that the findings are considerably more consistent when this procedure is followed.

101. Technique of determining imbalance.—*a. Determining sighting eye.*—For determining the sighting eye, a blank card about 13 by 20 centimeters, with a 1.5-centimeter round hole in the center is employed. The examinee is seated facing the spotlight 6 meters away; he grasps the card by the short side with both hands. While looking intently at the light, he slowly raises the card at arm's length and locates the light through the hole, and the eye selected for this purpose is the one used habitually for sighting and fixing.

b. Adjustment of trial frame.—In using equipment from the trial lens case, adjust the spectacle trial frame on the examinee so that it is comfortably worn and so that the cells are properly placed as to interpupillary distance.

c. Imbalance in horizontal meridian.—For determining an imbalance in the horizontal meridian, that is, exophoria or esophoria, place the Maddox rod in the cell before the nonsighting eye so that the axis of the rod is horizontal. Adjust the muscle lamp, or spot of light at 20 feet distance so that its diameter is about 1 centimeter, and switch off all lights in the vicinity of this area. Direct the examinee to fix upon the spot of light, and for a few seconds at a time alternately cover and uncover the nonfixing eye with an opaque card, allowing the fixing eye to maintain fixation constantly. The momentary covering of the nonfixing eye aids further in weakening of fusion control.

d. Orthophoria.—If orthophoria exists the visual line of the nonfixing eye will not deviate and the vertical line of light will be seen as passing through or bisecting the spotlight.

e. Heterophoria.—If heterophoria (in this case exophoria or esophoria) is present, the vertical line of light will be seen to the right or left of the spotlight.

f. Homonymous diplopia.—If the line of light is seen on the same side (homonymous diplopia) of the examinee as the Maddox rod is placed (for example, the Maddox rod before the left eye and the line is seen to the left of the spotlight), the qualitative diagnosis of esophoria is made, and in order to make a quantitative determination a prism must be used base out. Homonymous diplopia indicates esophoria, the amount of which is estimated by the use of a prism before the nonfixing eye, with base out or toward the temporal side. Place a weak prism, that is, of 1 diopter, before the nonfixing eye, and repeat the procedure of covering and uncovering the nonfixing eye. It will be found that perhaps the line of light has moved nearer the spot of light but still does not bisect it. Replace the prism with a stronger one until the line of light passes through the spot of light and the strength of the prism used indicates the amount of esophoria in prism diopters.

g. Crossed diplopia.—If the line of light is seen on the opposite side, as for example when the Maddox rod is before the left eye and the line is seen to the right (crossed diplopia), then a qualitative diagnosis of exophoria is made. A crossed diplopia indicates exophoria, the amount of which is estimated by the use of a prism before the nonfixing eye with base in or toward the nasal side. The procedure is the same as with esophoria except that the prism is used base in. The strength of the prism used to cause the line of light to bisect or pass through the spot of light indicates the amount of exophoria in prism diopters.

102. Optical principles involved in horizontal deviations.—*a. Orthophoria.*—The sighting eye fixes the spotlight; the nonsighting eye, having before it the Maddox rod, sees the spotlight as a vertical

line of light. If no deviation is uncovered (orthophoria), the rays of light from the spotlight will fall upon the foveae of both eyes and be projected into space to the point actually occupied by the light. When this occurs, the line of light will be seen passing directly through the spotlight.

b. Deviating eye.—As the Maddox rod possesses the power of weakening the action of the fusion centers, the eye behind the Maddox rod will deviate if it has a tendency to do so, provided the action of the fusion centers is reduced below the urge to deviate.

c. Esophoria.—Assuming the eyes have a tendency to deviate inward (esophoria), and the right eye is the nonsighting eye, the principles involved remain unchanged insofar as the sighting eye is concerned, but with the nonsighting (right eye in this case) they are different. The rays of light enter the eye as in orthophoria, but instead of falling upon the fovea they fall upon the retina on its nasal side. This occurs because the cornea is rotated inward, and the fovea is rotated outward. Therefore, following the law of projection, the image of the line of light being formed upon the nasal retina will be projected to the temporal field and will be seen as a vertical line upon the right side of the spotlight (homonymous diplopia).

d. Measurement of deviation.—In order to measure the amount of deviation that has been uncovered, prisms are utilized to refract the rays of light entering the deviating eye, outward or toward the temple until they fall upon the fovea. Rays of light passing through a prism are bent or refracted toward its base and the object seen through the prism is projected toward its apex. Therefore, increasing prisms placed base out before the deviating eye will refract the rays toward the temporal side, until they eventually reach the fovea, and at the same time the line of light will be seen to move over toward the nasal field until it passes directly through the spotlight. When this is accomplished the deviation is corrected by the refraction of the rays of light, the eye remaining stationary. The strength of prism required to accomplish this represents, in prism diopters, the amount of deviation uncovered at that time.

103. Vertical deviations.—*a. Hyperphoria.*—Ordinarily hyperphoria only is used as a diagnostic term where there exists a deviation of the visual lines in the vertical meridian, and the designation is made as to right or left, depending upon which of the visual lines is the higher, or which tends to deviate upward in comparison with its fellow. For the measurement of hyperphoria the Maddox rod is adjusted before the nonfixing eye with its axis vertical, hence the line of light is seen as horizontal. The nonfixing eye is alternately cov-

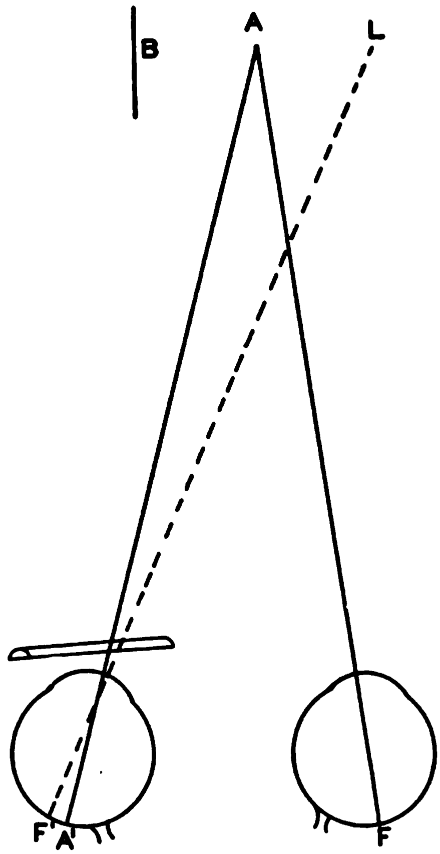
ered and uncovered, and if the line of light is seen passing through the spot of light there is no hyperphoria. If the line of light is seen below the spot of light there is a hyperphoria of the eye behind the Maddox rod, and the strength of prism used base down before this eye which causes the line to pass through, or bisect, the spot of light represents the deviation in prism diopters. If the line of light is seen above the spotlight a hyperphoria of the fixing eye is indicated, and the strength of prism base up before the eye behind the Maddox rod represents the amount of deviation in prism diopters. Suppose the right eye to be the fixing eye; the Maddox rod is adjusted with axis vertical in the spectacle trial frame. The left eye is covered and momentarily uncovered repeatedly. Further, suppose that, in this instance, when fusion is weakened the left visual line turns upward (left hyperphoria). Then with the left eye elevated, its fovea would be depressed and at a lower level than the fovea of the right eye. In this instance the image of the horizontal line of light would be formed above the fovea of the right eye, and when an image is formed above the fovea it is projected into the visual field below the point of fixation. Therefore, the examinee would see the spot of light with the right eye and the line of light with the left, and the line would be projected below the spot of light, indicating, in this case, a left hyperphoria. By using a prism of sufficient strength the position of the image of the line of light may be shifted from above the fovea to the level of the fovea, and the line of light will be seen as passing through the spot. The strength of the prism required indicates the amount of deviation in prism diopters.

b. Heterophoria.—Where the phorometer trial frame with rotary prism is used, in testing for heterophoria, the same procedure is used except that the examinee, by turning the milled thumbscrew controlling the rotary prism, adjusts the prisms himself so that the line of light passes through the spotlight. The nonfixing eye is alternately covered and uncovered. In horizontal deviations where the prism is adjusted base in (nasally) an exophoria is indicated, where the prism is adjusted base out (temporally) an esophoria is indicated.

c. Amount of deviation.—In vertical deviations the prism adjusted base down indicates a hyperphoria of the eye behind the Maddox rod. Where it is adjusted base up a hyperphoria of the opposite eye is indicated. In all instances the amount of deviation is read in prism diopters as the indicator shows on the markings on the rotary prism.

104. Heterophoria at 33 centimeters.—*a.* This test is not done routinely. The test is carried out in exactly the same manner as the test at 6 meters except that a small electric lamp (ophthalmoscope

without head) is held before the examinee at the level of his eyes. This is a test for imbalance at the ordinary reading distance, and may give the examiner some information as to the existence of refractive error, insufficiency of convergence, and may be indicative of a reduction of fusion control at usual reading distance. It will be frequently found that an examinee who shows a marked exophoria at 33 centimeters will also show a low angle of convergence, and under stress of fatigue may exhibit a diplopia (crossed) at reading distance.

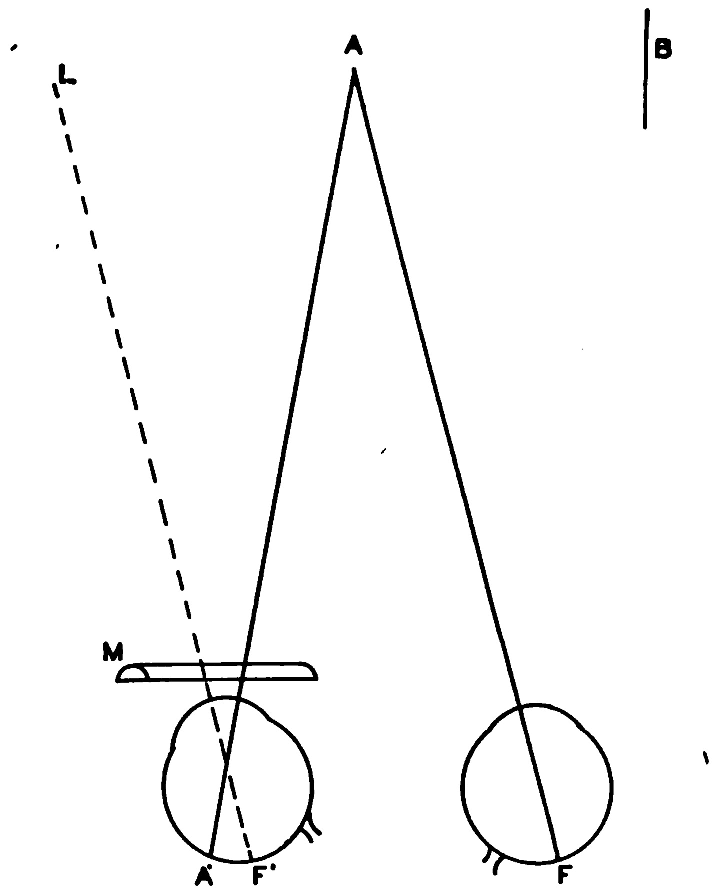


Right eye fixing *F'–L* in left visual axis, *F'* the left fovea. Image of *A* falls on *A'* to nasal side of fovea and is projected at *B*. Homonymous diplopia.

FIGURE 16.—Esophoria.

b. Cyclophoria.—The existence of a cyclophoria is not investigated as routine, but only when considered as necessary by the examiner. In testing for cyclophoria, two Maddox rods with the axes exactly vertical, one before each eye, may be used. With the spotlight at 20 feet a horizontal line of light is seen with each eye, and in order to prevent fusion, these may be separated by a strong prism (8 diopters) base up or down before one of the eyes. If there is a latent tendency

toward intorsion or extorsion in either eye, one of the lines will appear as at an angle with the other or slanted, and the eye intorted or extorted may be determined by the line that does not appear horizontal. For example, if the prism, base down, is before the left eye the upper line is the one seen with the left eye, etc. But with an intorsion the line of light will appear as slanting outward and downward, and with an extorsion the line will appear as slanting inward and downward.



Right eye fixing L–F', left visual axis. Image A falls on A', which is on temporal side of left fovea and therefore is projected at B. Crossed diplopia.

FIGURE 17.—Exophoria.

105. Etiology of heterophoria.—*a. Deviation.*—As previously stated the eyes are held in their proper positions in the orbits and in the proper relation to one another by the combined action of all of the extrinsic ocular muscles. Why one eye will deviate, when the action of the fusion centers is partially abolished, is not clear. There seems to be, for some reason or other, an urge of one or more of the

extrinsic muscles to overact or to underact. This action will cause the eyes to deviate from the parallel whenever released from control of the fusion centers.

b. Cause.—If the urge for binocular single vision is greater than the urge to deviate, the condition of heterophoria will exist; if the urge for binocular single vision is less than the urge to deviate, heterotropia will exist. If fusion control is habitually weak, or is easily weakened by artificial measures, the more significant will be deviation. If fusion control is active and not easily weakened, the existing latent deviation will be unimportant, at least under normal conditions. There must be taken into consideration, too, the possibility of anatomical defects. It may be that one muscle is actually longer or shorter than the normal.

c. Factors.—Whatever the primary cause of a latent deviation may be, certain factors tend to increase its tendency, and produce the condition of muscular asthenopia. Probably the most common factor encountered is an error in refraction, whether it be myopic, hyperopic, or astigmatic. This is particularly true when accumulative fatigue is superimposed. The fatigue may be induced by the refractive errors alone, or it may be secondary to them, originating in nervous or physical stress, chronic infection, etc.

d. Latent deviations.—Latent deviations of low degree, at 6 meters, such as 2 prism diopters of esophoria, 1 of exophoria, and ½ of hyperphoria, may be considered ordinarily as orthophoria. Latent deviations higher than these are in themselves of little significance, and can be considered worthy of attention only after all the associated factors which apply to the type of deviation have been investigated.

e. Factors to be considered.—(1) In all forms of latent deviations there must be considered:

(*a*) Ease with which fusion control is weakened.

(*b*) Efficiency with which visual lines are maintained parallel while moving in the six cardinal positions.

(*c*) Errors in refraction of one-half diopter or higher.

(2) If esophoria is exhibited there must be considered in addition to the above factors:

(*a*) Power of abduction (prism divergence).

(*b*) Amount of accommodation that can be exerted.

(3) If exophoria is exhibited, the power of adduction (angle of convergence or meter angle) must be taken into consideration in addition.

f. Increased tendency to deviate.—When the tendency to deviate increases, because of errors in refraction and fatigue, this increase

will be accompanied, generally, by defects in one or more of the associated factors, which apply to the type of deviation. The associated parallel movements are usually the first to exhibit evidences of ocular strain, which is manifested by diplopia in the primary, or in one or all of the cardinal positions on the tangential plane. For example, an individual exhibiting an exophoria of 2 prism diopters, a refractive error of 1 diopter, divergence power of 5 prism diopters, and an angle of convergence of 50°, may, after the onset of fatigue, exhibit a tendency to deviate 6 or 8 diopters, exhibit diplopia in the lateral positions on the tangential plane, and if fatigue continues, divergence power may increase to 10 diopters while the convergence power drops to 30°.

g. Return to original level.—After correcting the refractive error, thereby inducing ocular rest, all these factors tend to return to their original level, the defective parallel movements being the first to recover. Horizontal deviations respond much more readily after correction of existing refractive errors than do the vertical deviations.

h. Refractive errors.—It is a generally accepted theory that many cases of heterophoria are due entirely to refractive errors. It is believed, however, that all cases of heterophoria exist independent of refractive errors and that the errors, when fatigue is superimposed, only exaggerate the deviation without being the primary cause.

i. Accommodative theory.—The accommodative theory is as follows: Esophoria and exophoria are manifestations of muscular asthenopia due to hyperopia and myopia, respectively. This occurs because there is believed to be a definite relation or nervous balance between accommodation and convergence, with accommodation the dominating or controlling influence. In emmetropia, when the eyes accommodate 1 diopter, convergence is sufficient to cross the visual lines at 1 meter distance, that is, 1 meter angle of convergence is exerted, at which point the object focused upon is located. When this occurs the nervous balance between accommodation and convergence is equal.

j. Hyperopia.—In the hyperope accommodation exceeds convergence. In order to focus an object at 1 meter distance the eyes may have to accommodate sufficiently to focus a normal eye at 50 centimeters. When such accommodation occurs the eyes are still required to converge 1 meter angle, that is, the eyes are accommodating 2 diopters while converging only 1 meter angle. The excessive or unused stimulation to converge to 50 centimeters (2 meter angles) is present, and this may lead to convergence excess. In order to maintain binocular single vision the individual must overcome this convergence excess by increased action of his external recti muscles. which is initiated

by the fusion centers. When the action of the fusion centers is lowered, one eye will deviate inward as stimulation of the external recti is no longer great enough to maintain parallelism of the visual lines. Continuing further under accumulative fatigue, the external recti can no longer maintain their increased action; therefore, the convergence excess pulls one eye inward. This deviation will occur, in the early stages of fatigue, only when the eyes are turned in one or all of the cardinal positions, but in the more advanced stages deviation may occur while the eyes are in the primary position and independent of the action of the fusion centers.

k. Myopia.—In myopia the reverse occurs. Accommodation is less than convergence. When a myope fixes an object at 50 centimeters distance, he may be accommodating only enough to focus an emmetropic eye at 1 meter, that is, he is accommodating 1 diopter while converging 2 meter angles. When this occurs the urge to converge is weak, as accommodation is the dominating impulse. The external recti soon take advantage of the weak convergence stimulation and divergence excess results. When the action of the fusion centers is lowered one eye will deviate outward because of underaction of the internal recti, due probably to lowered muscular tonicity. Under accumulative fatigue the internal recti cannot overcome the pull of the external recti and deviation will occur; first, when the eyes are turned in one or all of the cardinal positions, and later, when in the primary position, independent of the action of the fusion centers (squint).

l. Actual findings.—Although the foregoing is the theory generally accepted in reference to heterophoria and squint resulting from errors in refraction, in actual practice it does not hold true at all times. Twenty-three cases with hyperopic errors exhibited esophoria in sixteen instances and exophoria in seven. All of these cases developed muscular asthenopic symptoms, under accumulative fatigue, with considerable increase in deviation. When the errors in refraction were corrected, symptoms disappeared and the deviations returned to their former levels. It will be noted that in this small series of cases above 30 percent of hyperopes exhibited exophoria which was influenced by the refractive errors.

106. Incidence of heterophoria.—In a series of 500 unselected cases, 244, or 48.8 percent, exhibited a horizontal imbalance above the amount considered as orthophoria; 132, or 25.6 percent, of this series exhibited a vertical imbalance; 25, or 10.24 percent, of the cases showing a horizontal imbalance exhibited, after the onset of fatigue, an increase in the deviation (or a greater amount could be uncovered), and developed defects in one or all of the associated factors.

107. Other methods of detecting heterophoria.—*a. Cover test.*—The examinee fixes the spotlight at 6 meters' distance. A card is held before one eye for a few seconds, then quickly removed. If exophoria exists the eye behind the card will deviate outward, and when the card is removed the eye will be seen to swing inward and take up fixation with the fixing eye. If esophoria exists the covered eye will deviate inward, and will swing outward when card is removed to take up fixation as in exophoria. The same applies to hyperphoria. This test is repeated by fixing an object or light at 33 centimeters' distance. This test cannot always be depended upon, as considerable heterophoria may exist before it can be exhibited by this method.

b. Diplopia or displacement tests.—(1) *Horizontal or lateral imbalance* (esophoria or exophoria).—The trial frame is adjusted to the examinee and a strong prism, 8 or 10 diopters, is placed base down before the right eye. The spot of light (muscle lamp) is seen at a distance of 20 feet and a diplopia is induced, the upper light being the image projected by the right eye and the lower light that projected by the left. If there is a condition of orthophoria the two images will be seen as separated in the vertical meridian only. In heterophoria there will be a lateral displacement of the two images as well as vertical. If the upper image is displaced to the right (homonymous diplopia), an esophoria is indicated, and if to the left, an exophoria. A quantitative determination is made with prisms, base in or out, in a manner similar to that where the Maddox rod is employed.

(2) *Vertical deviations.*—A strong prism is placed, base in, in front of the right eye (the prism must be of such strength that diplopia is induced, and as the eyes have a stronger converging than diverging power, base in is suggested). The image seen by the right eye will be displaced to the right (toward the apex of the prism), and if no hyperphoria exists the two images will be seen in the same horizontal plane. If the right image is higher than the left, a left hyperphoria is indicated; if the right image is lower than the left, condition is right hyperphoria. Where left hyperphoria is found the quantitative estimate may be made by prisms, placed base down before the left eye until both images are seen at the same level. In right hyperphoria the determination is made by prisms base up before the left eye until both images are at the same level (Peter).

c. Maddox double prism.—The Maddox double prism (two 4-diopter prisms, base together, in a trial lens frame) may be used in determining heterophoria. The Maddox double prism causes a monocular diplopia, an image being displaced toward the apex of each prism. When the spot of light is used at 20 feet with the Maddox double prism before one eye, three images are seen, the

upper and lower being images of the eye behind the double prism and the middle image that of the fellow eye. In orthophoria the three spots of light are seen in line; where heterophoria exists the middle image will appear displaced, that is, to right or left, above or below (depending upon the position of the double prism). Lateral and vertical deviations may be determined and prisms used to arrive at a quantitative conclusion.

d. Red lens test.—This test furnishes valuable corroborative evidence in examining for heterophoria and in some cases of heterotropia.

(1) The examinee is seated facing a blackboard, wall, or other flat surface at a distance of 75 centimeters. A red glass is placed in front of the right eye. Care should be taken to see that the glass is large enough and held in such position as to be in front of the pupil in all the movements of the eye.

(2) A small spotlight is now carried over the surface of the blackboard from the point of fixation along the eight cardinal meridians for a distance of 50 centimeters. In the normal individual the red and white lights remain fused as a pink light; in cases of heterophoria with low fusion; faulty; or in cases of actual heterotropia which do not suppress, a red and a white light will be seen. If the red glass is in front of the right eye and the red light is seen on the right side of the white light, then we have homonymous diplopia. If the red light appears on the left side, we have crossed diplopia.

(3) The position at which diplopia occurs can be reported in distances from the point of fixation or, by referring to the table in the chapter on the tangent rule, the distances in centimeters may be converted into degrees. Diplopia occurring within 50 centimeters of the point of fixation is considered to be disqualifying for flying applicants.

108. Associated factors.—As previously stated, the associated factors are vitally important in determining the significance of heterophoria. The factors to be considered are—

a. Power of abduction.

b. Power of adduction.

c. Associated parallel movements.

d. Accommodation.

e. Errors in refraction.

f. The power of fusion.

Only those factors pertaining to the recti muscles will be considered here. Accommodation and errors in refraction will be considered in their respective sections.

109. Power of abduction (prism divergence).—The normal power of abduction ranges between 3 and 6 prism diopters with an average of 4. When a low prism divergence is exhibited (below 4 diopters) associated with an esophoria, it indicates an overaction of the internal recti muscles, an underaction of the external recti, or both. At the same time, the power or urge of the fusion centers may be weak.

The examinee is seated facing a spotlight 6 meters away. The rotary prisms of the phorometer trial frame are adjusted before the eye so that when the milled screw operating the prism is turned toward the nose, the prisms will be acting base in, thereby placing the apex over the external rectus muscle. With the prism set at zero on the scale, the examinee should see but one spotlight. As the prisms are slowly rotated, base in, by the examiner, diplopia will be produced. The number of prism diopters which cause the onset of diplopia is read from the scale and entered on the record as abduction or prism divergence. The prisms should be turned steadily and at slow speed.

110. Optical principles involved.—The test is based upon the fact that the muscle lying beneath the apex of a prism is stimulated to action while the other remains passive, insofar as the action of the prism is concerned, and the urge of the fusion centers to maintain binocular single vision. Therefore, in this test care must be taken that the fusion sense is not impaired and that the prisms are accurately placed. The rays of light enter the eyes, fall upon the fovea of each, and the retinal images of the light are projected in the point actually occupied by the light, and appear as one. The prism being operated, base in, before one eye will refract the rays of light entering that eye toward the nasal side of the fovea. The fusion centers strive to maintain binocular single vision and in order to accomplish this the external rectus is stimulated to contract. This contraction rotates the cornea outward, and the posterior pole and fovea inward. In this way the refracted rays continue to fall upon the fovea and binocular vision is maintained. However, a point is reached, eventually, when the external rectus can no longer rotate the eye outward; the rays continue to be progressively refracted and soon travel beyond fovea, thus inducing diplopia. When diplopia occurs, the fusion centers instantly lose their urge for binocular single vision and the eye rotates back to its normal position. This test should not be repeated more than two or three times as the strain on the external rectus causes considerable discomfort.

111. Power of adduction.—There are three principal methods of measuring the power of adduction, namely—

a. Prism convergence.
b. Angle of convergence.
c. Meter angle.

The power of convergence should be, normally, three times as great as divergence, that is, 1 to 3, or 8 to 24.

112. Prism convergence.—This test is conducted in the same way as that for prism divergence except that the prism is placed base out, thereby placing the apex over the internal rectus. The results of this test are not as satisfactory as those of divergence, for there occurs a marked inconsistency in the findings. It is probable that the factor of accommodation plays an important part in convergence. The amount of accomodation with the muscle lamp at 20 feet is negligible.

113. Angle of convergence.—This method is much more satisfactory than prism convergence. The angle is computed from the near point of convergence (*PcB*) and interpupillary distance (*Pd*). The near point of convergence is represented by the symbol *PcB*, meaning the near point of convergence on the base line. The measurement is made from an imaginary line connecting the centers of rotation of the two eyes, situated 13.5 millimeters behind the anterior surface of the cornea. The point to be obtained is to determine the greatest amount of convergence that can be exerted and still maintain binocular single vision.

114. Near point of convergence.—The end of the Prince rule, or a modification of the same, is placed edge up at the side of the nose 11½ millimeters in front of the anterior surface of the cornea. A white-headed pin is held 33 centimeters in the median line above the edge of the rule, and the examinee is instructed to look at it intently. If both eyes are seen to converge upon the pin, it is then carried in the median line, along the edge of the rule, towards the root of the nose. The examinee's eyes are carefully watched, and the instant one is observed to swing outward the limit of convergence has been reached. The point on the rule opposite the pin is then read in millimeters. This test is repeated until a fairly constant reading is obtained. To the reading thus obtained 25 millimeters are added (the center of rotation is 13.5 mm. behind the cornea, and the end of the rule is placed 11.5 mm. in front of cornea, making in all 25 mm.), which gives the distance from the near point of convergence to the base line. The normal eyes should be able to converge to 80 millimeters or less. A near point more remote than 80 millimeters indicates an underaction of the internal recti.

115. Interpupillary distance.—*a.* The examiner stands with his back to the light, face to face with the examinee. The rule is laid

across the examinee's nose in line with his pupils, as close to the two eyes as possible. The distance is measured from the temporal side of one pupil to the nasal side of the other. The examiner closes his right eye and instructs the examinee to fix his eyes upon his open left. With the eyes in this position a predetermined mark on the rule is placed in line with the nasal border of the examinee's right pupil. The rule must be held steadily in this position while the examiner opens his right eye and closes his left. The examinee is then instructed to look at the open right eye. The point on the rule in line with the temporal border of the examinee's left pupil is read in millimeters, and the difference in millimeters between the two points on the rule is the interpupillary distance.

b. Angle of convergence.—The following formula is used to compute the angle of convergence: Angle of convergence equals one-half the interpupillary distance multiplied by 100 divided by the near point of convergence plus three, thus:

$$\frac{\frac{1}{2}\,Pd \times 100}{PcB} + 3 = \text{Angle of convergence}$$

The above formula for determining the angle of convergence is purely empirical, and it is not accurate from a standpoint of pure mathematics. It is fairly accurate when *PcB* and *Pd* are approximately equal. It is suggested that the table showing the angles of convergence with different findings as to *Pd* and *PcB* be used instead (see page 152), as this table is computed accurately from tables of tangents.

116. Meter angle.—*a. General.*—Another convenient method of determining the power of convergence is the employment of the meter angle. This method has all the advantages of the angle of convergence except that the interpupillary distance is not taken into consideration.

b. Unit of measurement.—The unit of measurement is obtained by the eyes fixing an object midway between the two eyes at a distance of 1 meter (1,000 mm.). The angle formed by a line joining the object with the center of rotation of either eye makes, with the median line, 1 meter angle. With an interpupillary distance of 64 millimeters, the above meter angle equals about 1.5°.

c. Near point of convergence.—The near point of convergence is determined as described under angle of convergence. When the number of millimeters obtained is divided into 1,000 the result will equal the number of meter angles of convergence exerted, thus: if the near point of convergence equals 100 millimeters, then $\frac{1{,}000 \text{ millimeters}}{100 \text{ millimeters}}$

equals 10 meter angles. Again, if the near point of convergence equals 50 millimeters, then $\frac{1{,}000 \text{ millimeters}}{50 \text{ millimeters}}$ equals 20 meter angles.

d. Convenience.—This method is especially convenient because, in the emmetrope, the amount of convergence reckoned in meter angles is exactly the same as the amount of accommodation reckoned in diopters.

117. Associated parallel movements.—*a. Applicability.*—This test is applicable almost exclusively to paresis and paralysis of the ocular muscles, and offers little information where latent errors are concerned.

b. Test.—The examinee stands near a window where good illumination falls on both eyes. The examiner holds a white-headed pin about 33 centimeters directly in front of the examinee's eyes and directs him to look at it steadily. Nystagmus in the primary position is to be noted at this stage of the test. The examinee is then instructed to hold his head still and watch the pin as it is moved slowly in the eight cardinal positions. Care is taken not to carry the pin beyond the field of binocular fixation. The eyes are inspected to discover any failure in fixing the pin. A lagging or overaction of either eye is noted.

c. Interpretation.—A lagging of either eye in any of the eight cardinal positions is due to an underaction of at least one of the extrinsic muscles. It may indicate a paresis or complete paralysis.

d. Recording.—The underaction is recorded by stating which eye lags and in which direction the lagging is observed. In the same way any overshooting of either eye is recorded by stating which eye is involved and in which direction.

e. Confirmation.—If any underaction or overaction is observed with this test the findings are confirmed on the tangent plane.

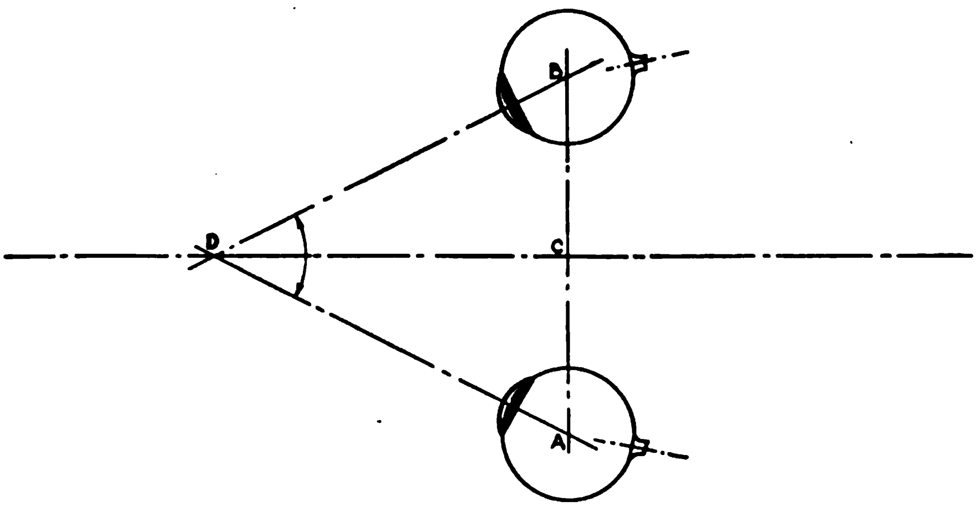
118. Squint.—*a. Definition.*—Squint or strabismus is a term which may be applied to those conditions where there is an obvious or manifest deviation of the visual axes from the normal. There are two general varieties of squint encountered:

(1) *Concomitant.*—Concomitant squint, or strabismus (heterotropia) which is characterized by the two visual axes, although abnormally directed, maintaining their relative position to one another with all ocular movements.

(2) *Paralytic.*—Paralytic squint or strabismus definitely due to a paresis or paralysis of one or more of the extrinsic ocular muscles, in which the two visual axes do not maintain their relative positions in all positions in the field of binocular fixation. There is another

type of squint due to a defective innervation in which there is an unequal stimulation, rather than paralysis, of conjugate muscles. This latter type may be encountered where there is an unequal stimulation of certain nerve centers as in meningitis, brain tumor, cerebral irritation as in epilepsy, etc.

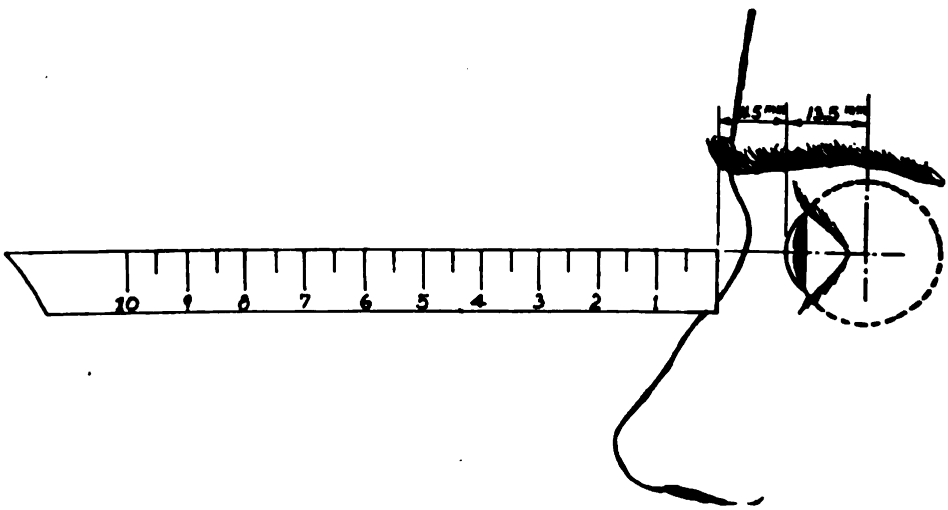
b. Concomitant squint (*heterotropia*).—As stated, in concomitant squint the visual axes retain their relation in all positions within the binocular field of fixation, differing in that respect from paralytic squint. In concomitant squint (this term is being more frequently employed clinically than heterotropia) there may be then a convergent type (esotropia), divergent type (exotropia), and deviation of the visual axes in the vertical meridian (hypertropia).



A Center of rotation, left eye.
B Center of rotation, right eye.
D Point of maximum convergence.
DC Distance from point of convergence to base line (*PcB*).
Interpupillary distance (*Pd*) is same as *AB*.
Angle of convergence, angle *ADB*.

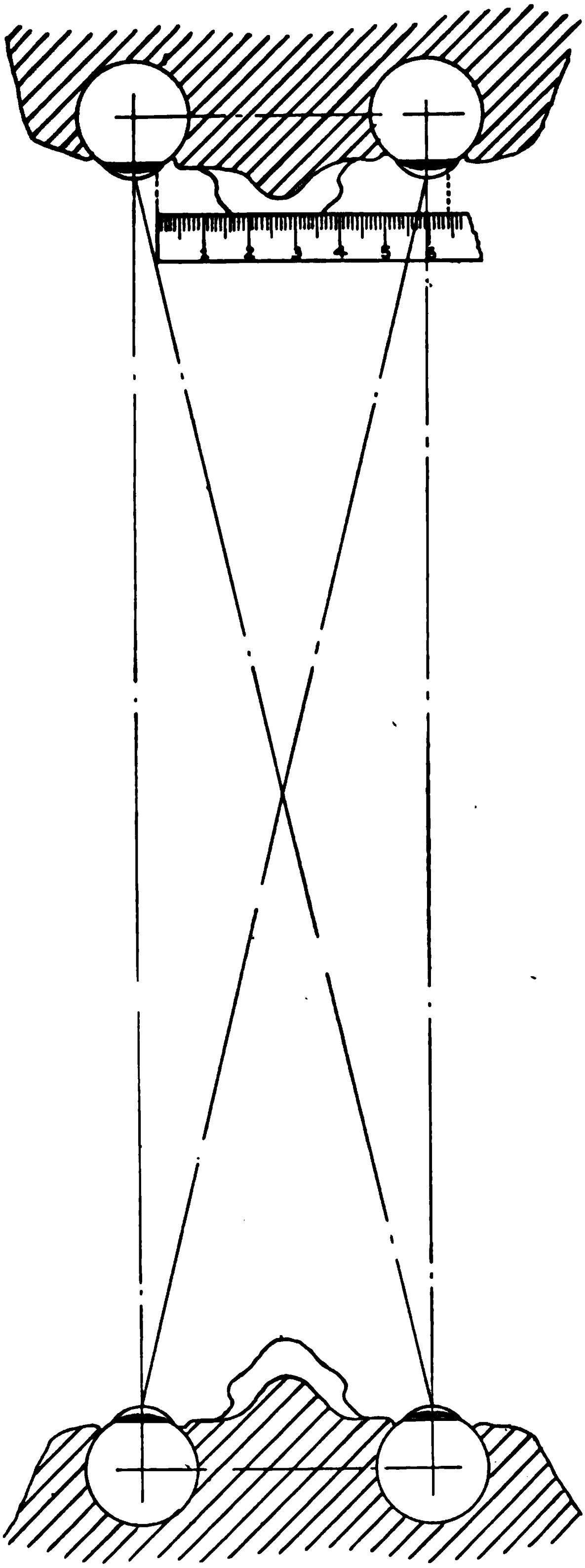
FIGURE 18.—Angle of convergence.

(1) *Convergent squint or esotropia.*—Space hardly permits a discussion of the etiological factors concerned in esotropia. Associated with such a condition are usually refractive errors, and a defective or absent fusion faculty. The deviating eye may be constant, that is, the deviation is always in the same eye (monocular esotropia), or it may be alternating. In either case the angle of deviation remains practically the same whatever position the fixing eye assumes. With convergent squint there is usually an amblyopia ex anopsia, either



End of rule is placed 11.5 millimeters in front of cornea, which is 13.5 millimeters in front of center of rotation. Therefore 25 millimeters is added to findings on rule in determination of *PcB*.

FIGURE 19.—Point of convergence on base line.



Examinee fixes upon left pupil of examiner, who places end of rule before nasal margin of right pupil of examinee. Examinee then fixes upon right pupil of examiner, who notes distance to temporal margin of left pupil of examinee. This distance is same as distance between centers of rotation of two globes.

FIGURE 20.—Measuring interpupillary distance.

congenital or acquired, of the deviating eye, especially in the monocular variety. With any variety of concomitant squint binocular single vision is impossible, so there must be either a diplopia or a suppression of the image of the deviating eye. The latter almost invariably occurs in concomitant squint. Therefore, the absence of diplopia is usually characteristic of any type of concomitant squint differing from paralytic type.

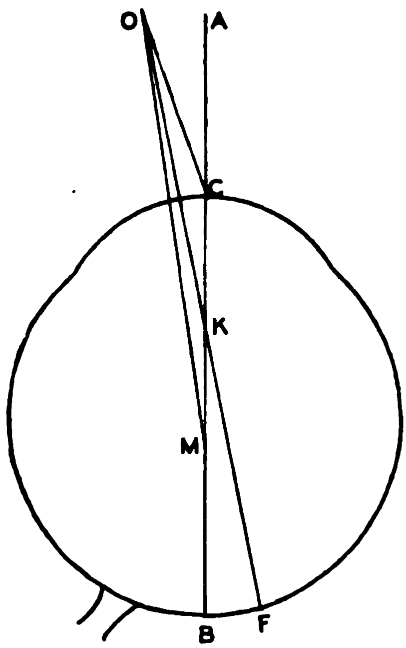
Esophoria and esotropia are closely allied, and in conditions of extreme stress as fatigue or toxemia, an esophoria may become manifest.

(2) *Divergent squint or exotropia.*—This is less frequently encountered than convergent. As with esotropia it may be monocular or alternating; the fusion faculty is usually weak and the angle of squint will be likely to vary at times. Exotropia differs from esotropia in that the latter more frequently responds to nonoperative treatment (correction of refractive errors). Diplopia rarely occurs.

(3) *Hypertropia.*—According to Peter, "A vertical deviation which exceeds the limits of hyperphoria is comparatively rare. In most instances such a deviation is not strictly concomitant, but paralytic in character." Such a deviation is usually due to a muscular anomaly, and may frequently be found coexistent with an esophoria or exophoria.

c. Kappa angle.—Even a marked appearance of squint does not necessarily indicate that a true squint actually exists, and the squint may be apparent only when the visual and optical axes do not coincide. The existence of a positive angle kappa will give the examinee the appearance of a divergent squint and a negative angle kappa will simulate a convergent squint. Usually a positive kappa angle is found with hyperopia and a negative angle with myopia. By the angle kappa is meant the angle formed by the intersection of the visual line with the geometric or optic axis, a line connecting the anatomical anterior and posterior poles of the eye. The angle kappa is of clinical value and has an important bearing on the accurate measurement of the angle of squint. The angle kappa can be measured on the perimeter; the eye not being examined is occluded; the other is carefully centered on the fixation point of the perimeter. The examiner rotates the arc of the perimeter until it is in the horizontal position; a small electric light bulb (ophthalmoscope without head) is held at the point of fixation and the examiner determines the position of the reflex of the light on the cornea. If the reflex is exactly within the center of the pupil (with the examiner sighting directly behind the light), the visual and optic axes coincide and the kappa angle does not exist. If the reflex is seen on the inner or

nasal side of the center of the pupil, kappa angle is positive; the light is slowly moved along the arc of the perimeter in the temporal field until its reflex is seen exactly at the center of the pupil, the eye continuing to fix on the fixation point of the perimeter; the number of degrees read off on the arc of the perimeter indicates the value of the positive kappa angle. If the reflex is seen on the temporal side of the center of the pupil, kappa angle is negative and may be measured by moving the light in the nasal field until it reaches the center of the pupil.



F, FOVEA.
M, CENTER OF ROTATION.
K, NODAL POINT.
AB, OPTIC OR GEOMETRIC AXIS.
O, POINT OF FIXATION.
OF, VISUAL AXIS, OR LINE.
ANGLE OCA IS ANGLE KAPPA.
ANGLE OKA IS ANGLE ALPHA.
ANGLE OMA IS ANGLE GAMMA.

FIGURE 21.—Measuring angle of squint.

In the emmetropic eye angle kappa is usually slightly positive, and in hyperopia it may be markedly positive, as much as 5° or more, which would cause an appearance of a divergent squint of 10° or more, as the case may be, when both eyes are casually inspected. Thus an individual may actually have a squint which is not apparent. On the other hand, he may present the appearance of a marked squint and yet have a condition of orthophoria.

d. Measuring the angle of squint.—(1) *Hirschberg method.*—There are several methods of determining the deviation of the squinting eye, the simplest of which is, perhaps, the Hirschberg method. A small lamp is held before the examinee and the position of its reflex on the cornea is noted, if the reflex is noted on the pupillary edge (outer edge in convergence, inner in divergence), the deviation may be estimated as about 15°. When the reflex is halfway between the pupillary border and limbus the deviation is approximately 35°, and when the reflex is seen at the limbus the deviation may be estimated at 45°.

(2) *Perimeter method.*—The perimeter may be used to measure the amount of deviation in squint. This method is quite accurate but the value of angle kappa must be taken into consideration. The chin rest of the perimeter is adjusted so that the squinting eye is opposite the point of fixation. The examinee is directed to fix upon a point at least 20 feet away, immediately above the point of fixation. The small light, as used in measuring angle kappa, is moved along the arc of the perimeter until its reflex is exactly in the center of the pupil of the squinting eye. The position of the light on the arc of the perimeter indicates the number of degrees of deviation.

e. Paralytic squint.—(1) *General.*—A paralysis of any one of the extrinsic ocular muscles will result in a limitation in the rotation of the globe in the direction of the action of that muscle. Instead of a complete paralysis there may be a slight paresis and the defect of motility may be so slight that it is not recognized upon ordinary inspection.

(2) *Detection.*—Limitation of movements of the globe may be detected in the manner described in paragraph 117, provided they are gross enough to be easily noticed. When the limitation is slight they may escape detection without the employment of special tests.

(3) *Characteristic symptom.*—There is one characteristic symptom, or subjective manifestation of paralytic squint, that the patient practically invariably complains of—diplopia; it is a valuable point in differentiating concomitant and paralytic squint. Unlike concomitant squint the affected eye does not have its image suppressed, and the character of the diplopia in the different parts of the normal field of binocular fixation aids the examiner tremendously in arriving at a diagnosis as to the muscle, or muscles, involved.

(4) *Differentiation between physiologic and pathologic diplopia.*—Physiologic diplopia has been referred to repeatedly in connection with stereoscopic vision, and is considered as being a regular accompaniment of normal binocular vision. Alexander Duane differentiated between physiologic and pathologic diplopia, emphasizing the

characteristics of each, in a manner that will be found to be extremely helpful to the student of ophthalmology. The following table is taken from his article "Diplopia and other Disorders of Binocular Projection," appearing in the *Archives of Ophthalmology*, volume 7, February 1932.

Physiologic diplopia	Pathologic diplopia
The object of fixation appears single and is distinct.	The object of fixation appears double, one image being distinct, the other indistinct.
The only objects seen double are those that are obviously farther or nearer than the object of fixation. The nearer the objects are to the latter, the less double they appear, and those that are alongside it appear single.	Most of the objects in the field of view appear double, but particularly those that are close to the object of fixation and are alongside it.
The diplopia is hardly ever recognized spontaneously and rarely causes confusion.	Diplopia often obtrudes itself on the notice and often causes confusion and discomfort.
If an object is seen double, both images are indistinct, and are also shadowy or ghost-like, so that if one is in direct line with the object of fixation, the latter can be seen through it.	When an object is seen double, one image has the natural appearance of the object itself; the other is more or less indistinct and shadowy.
The diplopia is not affected by shifting the gaze laterally or vertically, provided the convergence is unaltered.	The diplopia is often increased or diminished by shifting the gaze sideways or up and down.
The diplopia can be made to disappear at once by changing the convergence, so as to fix an object nearer or more remote, as the case may be.	Frequently the diplopia remains when the convergence is altered.

f. Symptomatology of paralytic squint.—(1) *Deviation.*—When one of the lateral recti is paralyzed, and its direct antagonist intact, the eye will deviate toward the side of the intact antagonist, that is, away from the side of the paralyzed muscle. If the degree of involvement of the affected muscle be slight the deviation may not be appreciable upon casual inspection. However, it can usually be determined by the use of the perimeter and small light, the corneal reflex being noted. A paralysis of one of the vertically acting muscles is even less noticeable upon inspection, due to the compensatory action of its synergist. The position of corneal reflex usually will show a deviation that is not obvious. The cover test will be found

to be of value in deviations of paralytic origin, but it does not differentiate heterophoria.

(2) *Primary and secondary deviation.*—When directed to fix upon an object in the distance, the examinee with paralytic squint will fix with the unaffected eye almost invariably, and the eye having a paralyzed muscle will deviate. The deviation in this instance is designated as primary. If the unaffected eye is covered, and he is directed to fix upon the distant object, the unaffected eye will assume the position the affected eye assumed in primary deviation, or assume secondary deviation. Secondary deviation is greater, or more accentuated, than primary deviation. Quoting Peter directly,

> The reason for the difference in deviation is as follows: The innervation required of the non-paralyzed eye to fix when the paretic eye is covered, is a normal innervation, the paralytic eye simply failing to follow in this conjugate movement because the yoke muscle is paralyzed. In secondary deviation when the paralytic eye fixes in primary position or "eyes front," a greater effort is required to hold this eye in position because of the paralytic muscle, and this same excess of energy goes into the yoke muscle of the non-paralytic eye causing it to deviate excessively. For example, if the right internal rectus is paralyzed, in the cover test or without the cover test, the right eye will deviate to the right while the left eye fixes. In secondary deviation, if the cover is applied to the left or normal eye, and the right eye is forced into fixation, it will be noted that the left eye will be turned to the left, and to a greater extent than was the primary deviation of the right.

It is to be remembered that the amount of rotation of the globe in one direction is not altogether abolished by the paralysis of a muscle, but is lessened only, providing the action of that muscle's synergist is still affected.

(3) *Determination of limitation of globe movement.*—In paralytic squint there is a limitation in the movement of the globe in the direction of action of the paralyzed muscle. This limitation may be determined objectively by actual perimetric measurements, that is, fixation on a small electric light which is moved on the arc of the perimeter and the position of the corneal reflex noted; or subjectively, by moving a small card with a few test letters along the arc of the perimeter, keeping the head fixed and noting the position where blurring occurs (beyond the limit of fixation the retinal image will not be on the fovea, consequently will not be clearly defined). The most peripherally located letter on the card should be used, and the amount of rotation in eight positions of the arc of the perimeter noted, or more as considered necessary, in the direction of the field of action of the paralyzed muscle. The results may be plotted on any ordinary perimetric chart, and a comparison made with the normal field of fixation or with the field of fixation of the unaffected eye.

The limitation in the field of fixation is a valuable point in differentiating concomitant and paralytic squint. The meridian in which the limitation is found indicates the muscle that is paretic.

g. False projection and diplopia.—(1) *General.*—As has been stated, diplopia is a symptom almost invariably complained of by the patient with paralytic squint, and is rarely encountered in the concomitant type. Frequently, where there exists a diplopia, the patient has considerable difficulty in determining which is the true and which is the false image. The tangent screen, in conjunction with a red glass before one eye, greatly facilitates the determination of the muscle at fault. By the use of the red glass there may be determined the relative position of the two images in position of "eyes front," the direction of movement in which there occurs the greatest separation, whether or not the diplopia is in the horizontal or vertical plane (or both), and the type of diplopia in the horizontal plane, that is, whether crossed or homonymous. The method of use of the red lens test has already been described. The red glass before one eye causes a red image upon the retina of that eye, and the projection of its image upon the screen is noted by the examiner as to the right or left, or above or below the image seen by the fellow eye. In the diplopia of paralytic squint the false image is always the image more distally located, or peripherally projected upon the tangent screen, and by the use of the red glass it can be determined to which eye the false image belongs. For example, consider a paralysis of the right external rectus; the examinee has before his right eye the red glass; the small light is moved along the screen horizontally toward the examinee's right. A diplopia is noted, and the separation increases as the light moves toward the right side of the screen. The red image will be seen to the right of the white image (homonymous diplopia), and as the light is moved to the right the two images will become more widely separated. When the right eye has reached its maximum degree of abduction (by action of the synergists of the right lateral rectus) the retinal image of the light (red as it is seen through the glass) moves away from the right fovea on the nasal side of the retina, and is projected falsely in the right temporal field. As the light is moved in the cardinal directions of the action of each of the six extrinsic muscles, the relative positions of the red and white images indicate the muscle at fault. The false image is the image more distally located, and it is displaced in the direction of action of the affected muscle.

(2) *Red glass equipment.*—It is suggested that the frame of an ordinary "antiglare" goggle, or automobile goggle, be used with

the tangent screen. The left lens may be removed altogether and the right replaced with a red lens. A lens of this size is more satisfactory than an ordinary 1½-inch red lens from the trial lens case, as it affords a greater field.

(3) *Torsion.*—In paralysis of the extrinsic muscles, an oblique position of the false image may be noted, which indicates a torsion.

(4) *Disturbances.*—Vertigo, dizziness, and even nausea with vomiting, may be complained of by the patient with paralytic squint, particularly where there is a vertical diplopia or a torsion. Lateral displacement is less likely to give rise to such reflex disturbances.

(5) *Symptom.*—A prominent symptom of paralytic squint, and one that is easily accounted for, is an abnormal rotation of the head. This may be evidenced by face rotation and tilting of the head in order to avoid a diplopia and its annoying accompaniments. In paralyses of the medial and lateral recti the face is turned toward the field of action of the paralyzed muscle. For example, in paralysis of the right external rectus the patient in fixing on an object will turn his head to the right; by so doing he may adduct his right eye and avoid a diplopia which may occur in fixing on an object directly ahead, or certainly would occur if looking at an object to the right. The medial and lateral recti are mentioned in this instance as each of these two muscles has no subsidiary action. In the case of each of the other extrinsic ocular muscles, the face turns toward the normal maximum vertical pull of the paralyzed muscle. Where there exists a torsion of the false image there will likely be an associated tilting of the head to the right or left.

(6) *Manifestations.*—Below is a summary of the objective and subjective manifestations of paralyses of the individual ocular muscles:

(*a*) *Right external rectus.*

Primary deviation.—Right eye deviates to left.
Secondary deviation.—Left eye deviates to right.
Limitation in movement toward right.
False projections.—Toward right, homonymous diplopia, accentuated in right temporal field.
Face turned to right.

(*b*) *Right internal rectus.*

Primary deviation.—Right eye deviates to right.
Secondary deviation.—Left eye deviates to left.
Limitation in movement to left, nasalward.
Crossed diplopia, accentuated toward left.
Face turned to left.

(*c*) *Right superior rectus.*

Primary deviation.—Right eye displaced down and out with some extorsion.

Secondary deviation.—Left eye up and to left.

Limitation of movement up and to right.

Vertical with some crossed diplopia, increasing up and to right.

Face turned up and head tilted to left shoulder.

(*d*) *Right inferior rectus.*

Primary deviation.—Up and out with some intorsion.

Secondary deviation.—Left eye down and to left.

Limitation of movement down and to right.

Vertical with some crossed diplopia, increasing down and to right.

Face turned down and to right, and head tilted toward right shoulder.

(*e*) *Right superior oblique.*

Primary deviation.—Right eye deviates to left with some extorsion.

Secondary deviation.—Left eye down and to right.

Limitation of movement down and to left.

Vertical diplopia accentuated on looking down and to left.

Face turned down and to left, head tilted toward left shoulder.

(*f*) *Right inferior oblique.*

Primary deviation.—Downward and inward with intorsion.

Secondary deviation.—Left eye up and to right.

Limitation of movement up and to left.

Vertical diplopia accentuated up and to left.

Face turned up and to left, with head tilted to right shoulder.

(*g*) *Left external rectus.*

Primary deviation.—Left eye turns to right.

Secondary deviation.—Right eye turns to left.

Limitation of movement toward left.

Homonymous diplopia accentuated in left temporal field.

Face turned to left.

(*h*) *Left internal rectus.*

Primary deviation.—Left eye deviates to left.

Secondary deviation.—Right eye deviates to right.

Limitation of movement toward right.

Crossed diplopia accentuated toward right.

Face turned to right.

(*i*) *Left superior rectus.*

Primary deviation.—Down and to left.

Secondary deviation.—Right eye up and to right.

Limitation of movement up and to left.

Vertical diplopia accentuated up and to left.

Face turned up and to left, and head tilted toward right shoulder.

(*j*) *Left inferior rectus.*

Primary deviation.—Left eye deviates up and to left.

Secondary deviation.—Right eye down and to right.

Limitation of movement down and to left.

Vertical diplopia accentuated down and to left.

Face turned down and to left, and head tilted toward left shoulder.

(*k*) *Left superior oblique.*

Primary deviation.—Left eye deviates up and to right with some extorsion.

Secondary deviation.—Right eye deviates down and to left.

Limitation of movement down and to right.

Vertical diplopia accentuated down and to right.

Face down and to right, and head tilted toward right shoulder.

(*l*) *Left inferior oblique.*

Primary deviation.—Left eye deviates down and to right with some intorsion.

Secondary deviation.—Right eye deviates up and to left.

Limitation of movement up and to right.

Vertical diplopia accentuated up and to right.

Face turned up and to right, with head tilted toward left shoulder.

119. Complete oculomotor paralysis.—The third nerve supplies all of the extrinsic ocular muscles except the external rectus and superior oblique. In addition, it also has branches, by way of the ciliary ganglion, to the sphincter fibers of the iris and the ciliary muscle. A complete paralysis of the oculomotor nerve would, then, be evidenced by—

a. Internal opthalmoplegia.—Dilated pupil not responding to light, convergence, or accommodation, and paralysis of accommodation, or cycloplegia.

b. Ptosis.—Loss of action of the levator which is innervated by a branch of the superior division of the third nerve.

c. Primary deviation.—Globe rotated downward and outward with some intorsion due to the unopposed action of the superior oblique and external rectus.

d. Crossed diplopia which increases on looking toward the normal side.

e. The face will be turned toward the normal side and upward. This may not occur, as the ptosis is usually so complete as wholly to obscure the vision of the affected eye.

It is quite obvious that any degree of squint, either concomitant or paralytic, should be considered as disqualifying for flying duty, as with such a condition binocular single vision is impossible, certainly within the normal field of binocular fixation. The résumé of the principal features or characteristics of the varieties of squint is included in order that the examiner may make an intelligent interpretation of his findings. The student is cautioned against the use of symptomatic terms in the place of actual diagnosis, and again he is admonished against jumping at conclusions and too hastily arriving at a diagnosis.

Table for computing angle of convergence

Pd Ordinates—*PcB*
Abscissae—Interpupillary distance

PcB	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75
	Angle																				
40	69	69	71	72	73	74	75	76	76	77	78	79	80	81	82	82	83	84	85	86	86
41	68	69	70	71	71	72	73	74	75	76	77	78	78	79	80	81	82	83	83	84	85
42	66	67	68	69	70	71	72	73	74	75	75	76	77	78	79	80	80	81	82	83	84
43	65	66	67	68	69	70	71	72	72	73	74	75	76	77	78	78	79	80	81	81	82
44	64	65	66	67	68	69	69	70	71	72	73	74	75	75	76	77	78	79	79	80	81
45	63	64	65	66	66	67	68	69	70	71	72	72	73	74	75	76	76	77	78	79	80
46	62	63	64	64	65	66	67	68	69	70	70	71	72	73	74	74	75	76	77	78	78
47	61	62	62	63	64	65	66	67	68	68	69	70	71	72	73	73	74	75	76	76	77
48	60	60	61	62	63	64	65	66	67	67	68	69	70	71	71	72	73	74	74	75	76
49	59	59	60	61	62	63	64	65	65	66	67	68	69	70	70	71	72	73	73	74	75
50	58	58	59	60	61	62	63	64	64	65	66	67	68	68	69	70	71	72	72	73	74
51	57	58	58	59	60	61	62	63	63	64	65	66	67	67	68	69	70	70	71	72	73
52	56	56	57	58	59	60	61	62	62	63	64	65	66	66	67	68	69	69	70	71	72
53	55	56	56	57	58	59	60	61	61	62	63	64	65	65	66	67	68	68	69	70	71
54	54	55	56	56	57	58	59	60	60	61	62	63	64	64	65	66	67	67	68	69	70
55	53	54	55	56	56	57	58	59	60	60	61	62	63	63	64	65	66	66	67	68	69
56	52	53	54	55	56	56	57	58	59	59	60	61	62	62	63	64	65	65	66	67	68
57	51	52	53	54	55	56	56	57	58	59	59	60	61	62	62	63	64	64	65	66	67
58	51	52	52	53	54	55	56	56	57	58	58	59	60	61	61	62	63	64	64	65	66
59	50	51	52	52	53	54	55	55	56	57	58	58	59	60	61	61	62	63	63	64	65
60	49	50	51	52	52	53	54	55	55	56	57	58	58	59	60	60	61	62	63	63	64
61	48	49	50	51	52	52	53	54	55	55	56	57	58	58	59	60	60	61	62	62	63
62	48	49	49	50	51	52	52	53	54	54	55	56	57	57	58	59	60	60	61	62	62
63	47	48	49	49	50	51	52	52	53	54	54	55	56	57	57	58	59	59	60	61	62
64	46	47	48	49	49	50	51	52	52	53	54	54	55	56	57	57	58	59	59	60	61
65	46	47	47	48	49	50	50	51	52	52	53	54	55	56	56	57	57	58	59	59	60
66	45	46	47	47	48	49	50	50	51	52	52	53	54	55	55	56	56	57	58	59	59
67	45	45	46	47	47	48	49	50	50	51	52	52	53	54	54	55	56	57	57	58	58
68	44	45	45	46	47	48	48	49	50	50	51	52	52	53	54	54	55	56	56	57	58
69	43	44	45	46	46	47	48	48	49	50	50	51	52	52	53	54	54	55	56	56	57
70	43	44	44	45	46	46	47	48	48	49	50	50	51	52	52	53	54	54	55	56	56

Table for computing angle of convergence—Continued

Pd Ordinates—*PcB*
Abscissae—Interpupillary distance

PcB	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75
	Angle																				
71	42	43	44	44	45	46	46	47	48	49	49	50	50	51	52	52	53	54	54	55	56
72	42	42	43	44	45	45	46	47	47	48	49	49	50	50	51	52	52	53	54	54	55
73	41	42	43	43	44	45	45	46	47	47	48	49	49	50	51	51	52	52	53	54	54
74	41	41	42	43	43	44	45	45	46	47	47	48	49	49	50	51	51	52	52	53	54
75	40	41	42	42	43	44	44	45	46	46	47	48	48	49	49	50	51	51	52	52	53
76	40	40	41	42	42	43	44	44	45	46	46	47	48	48	49	49	50	51	51	52	53
77	39	40	41	41	42	43	43	44	44	45	46	46	47	48	48	49	49	50	51	51	52
78	39	39	40	41	41	42	43	43	44	45	45	46	46	47	48	48	49	50	50	51	51
79	38	39	40	40	41	42	42	43	43	44	45	45	46	47	47	48	48	49	50	50	51
80	38	39	39	40	40	41	42	42	43	44	44	45	45	46	47	47	48	48	49	50	50
81	37	38	39	39	40	41	41	42	42	43	44	44	45	46	46	47	47	48	48	49	50
82	37	38	38	39	40	40	41	41	42	43	43	44	44	45	46	46	47	47	48	48	49
83	37	37	38	38	39	40	40	41	42	42	43	43	44	44	45	46	46	47	47	48	49
84	36	37	37	38	39	39	40	40	41	42	42	43	44	44	45	45	46	46	47	48	48
85	36	36	37	38	38	39	39	40	41	41	42	42	43	44	44	45	45	46	46	47	48
86	35	36	37	37	38	38	39	40	40	41	41	42	43	43	44	44	45	45	46	47	47
87	35	36	36	37	37	38	39	39	40	40	41	42	42	43	43	44	44	45	45	46	47
88	35	35	36	36	37	38	38	39	39	40	41	41	42	42	43	43	44	44	45	46	46
89	34	35	36	36	37	37	38	38	39	40	40	41	41	42	42	43	43	44	44	45	46
90	34	35	35	36	36	37	37	38	39	39	40	40	41	41	42	42	43	44	44	45	45
91	34	34	35	35	36	36	37	38	38	39	39	40	40	41	41	42	43	43	44	44	45
92	33	34	34	35	36	36	37	37	38	38	39	39	40	40	41	42	42	43	43	44	44
93	33	33	34	35	35	36	36	37	37	38	38	39	40	40	41	41	42	42	43	43	44
94	33	33	34	34	35	35	36	36	37	38	38	39	39	40	40	41	41	42	42	43	43
95	32	33	33	34	34	35	36	36	37	37	38	38	39	39	40	40	41	41	42	42	43
96	32	32	33	34	34	35	35	36	36	37	37	38	38	39	40	40	41	41	42	42	43
97	31	32	33	33	34	34	35	35	36	36	37	38	38	39	39	40	40	41	41	42	42
98	31	32	32	33	33	34	34	35	36	36	37	37	38	38	39	39	40	40	41	41	42
99	31	32	32	33	33	34	34	35	35	36	36	37	37	38	38	39	39	40	40	41	41
100	31	31	32	32	33	33	34	34	35	35	36	36	37	37	38	38	39	40	40	41	41
101	30	31	32	32	33	33	34	34	35	35	36	36	37	37	38	38	39	39	40	40	41
102	30	31	31	32	32	33	33	34	34	35	35	36	36	37	37	38	38	39	39	40	40
103	30	30	31	31	32	32	33	34	34	35	35	35	36	37	37	38	38	39	39	40	40
104	30	30	31	31	32	32	33	33	34	34	35	35	36	36	37	37	38	38	39	39	40
105	29	30	30	31	31	32	32	33	33	34	34	35	35	36	36	37	37	38	38	39	39

SECTION XVI

ACCOMMODATION

120. Changes in dioptric power.—*a.* In the normal, or emmetropic eye, the dioptric system is so arranged that rays of light coming from a point at infinity (or to all intents and purposes beyond 20 feet) are focused on the retina and a single cone of the fovea may be stimulated. For practical purposes it may be considered that rays of light from a point 20 feet or farther away are parallel, but from a nearer point the rays will be divergent, and in order that they be seen clearly some change must take place in the dioptric power of the eye, otherwise they will be focused behind the retina, resulting in a poorly defined image, due to the stimulation of many cones. Obviously, the change that occurs in the dioptric power of the eye must be an increase, that is, the lens system becomes stronger or more convex.

b. "Moving the object from infinity to 5 meters moves the position of the image only 0.06 millimeters. Since the sensitive layer of the retina is just about that thickness the image will still be in focus. No perceptible blur occurs until the object moves within 5 meters. When this happens the focus falls behind the retina and in place of a clear image we now have blurred diffusion circles falling on the rods and cones. In order to have a clear focus once more, either the dioptric power of the eye must increase, or the eyeball must become longer." (Adler, *Clinical Physiology of the Eye.*)

c. In the human eye there is an increase in dioptric power caused by a change in the contour of the crystalline lens, resulting from contraction of the ciliary muscle. The change in contour occurs principally on the anterior surface, which becomes more convex. The amount of increase depends directly upon the nearness of the point of fixation. This phenomenon (the power of increasing the dioptric power of the lens) is called accommodation, and it is this factor that enables us to see near objects clearly.

d. It is hardly worth while to discuss at this point the various theories as to the method of accommodation. It is apparent that no one theory wholly explains the phenomenon in every respect. As

has been stated, accommodation is accomplished by contraction of the ciliary muscle which is innervated by the third nerve (oculomotor). It is interesting to note that accomodation is accompanied by contraction of the pupil (the sphincter fibers of the iris having the same innervation) which further aids in sharper definition of the retinal image.

121. Amplitude of accommodation.—The amplitude of accommodation (A) may be defined as the difference between the dioptric power of the eye when accommodation is completely relaxed (static refraction) and when it is exerted to its utmost (dynamic refraction). In determining the amplitude of accommodation, the far point and the near point are taken into consideration. By the far point (punctum remotum) is meant the farthest distance away in meters an object can be seen distinctly, and as accommodation is measured in diopters, it is customary to convert this distance into the dioptric equivalent, the refractive power being the reciprocal of the focal distance in meters. The dioptric power of the eye with accommodation relaxed represents the static refraction of the eye and may be represented by R. The nearest point seen distinctly with a maximum of accommodation exerted is referred to as the near point (punctum proximum). The dioptric power with accommodation utilized to its greatest extent (the dynamic refraction of the eye) is represented by P. Thus the amplitude of accommodation may be represented by the difference between refraction with extreme accommodation and accommodation completely relaxed, thus $A=P-R$.

122. Far and near points.—*a. Emmetropia.*—In emmetropia the far point is located at infinity, the dioptric value of which is nil or may be considered as zero. $A=P-R$, or $A=P$, and the amplitude of accommodation is represented by the dioptric value of the near point. For example, if the near point is at 10 centimeters (10/100 meter) the amplitude of accommodation is 10 diopters, the dioptric equivalent of this distance.

b. Myopia.—In myopia R has a positive value; the far point is located at some point nearer than infinity; divergent rays of light from this point converge upon the retina with accommodation relaxed (ref. conjugate foci). For example, let us consider a myope whose far point is at 1 meter distance (R in this case is 1 diopter), and whose near point is 10 centimeters.

$$\begin{aligned} A &= P-R \\ &= \frac{100}{10}-\frac{100}{100} \\ &= 10-1=9 \end{aligned}$$

There is an amplitude of accommodation in this instance of 9 diopters, although the near point is at the same distance as that of the emmetrope referred to above

c. Hyperopia.—In hyperopia R is a negative quantity.

Therefore
$$A=P-(-R)$$
$$=P+R$$

If an individual is hyperopic to the extent of two diopters, he must exercise two diopters of accommodation at infinity. Further, suppose that his near point is at 10 centimeters,

$$\begin{aligned} A &= P-(-R) \\ &= \frac{100}{10}-\frac{(-100)}{50} \\ &= 10+2=12 \end{aligned}$$

thus it is found that his amplitude of accommodation to be 12 diopters, although his near point is identical with the emmetrope and the myope considered above.

d. Therefore consideration must be given to the error of refraction an individual may have in conjunction with the dioptric equivalent of his near point in determining the amplitude of accommodation. In myopia the refractive error must be subtracted from, and in hyperopia it must be added to, the dioptric equivalent of the near point in order to make an accurate estimate of the amplitude of accommodation. However, in the examination of Air Corps personnel this is not done routinely because the standards regarding allowable errors of refraction are within 1 diopter.

123. Influence of age upon amplitude of accommodation.—The amplitude of accommodation progressively decreases with age. This phenomenon is ordinarily considered as a physiological rather than pathological process. In youth the lens may be considered as a capsule filled with a gelatinous fluid, and is capable of an extreme amount of elasticity. With advancing age there is a steadily progressive hardening or sclerosing process until finally the lens contour is practically fixed and incapable of any change. When the near point of accommodation recedes to 22 centimeters, the individual is considered as entering into the presbyopic stage. It is thought that in order to accommodate easily and without inducing asthenopia there must be about 1½ diopters excess of accommodative power that is not called into use. Therefore, a recession of the near point beyond 22 centimeters reduces the accommodation, and reading must be carried on at a distance greater than 33 centimeters. Eventully, the loss of accommodative power must be replaced by lenses of the proper strength in order that near objects may be seen distinctly. It is

obvious that the hyperope is more hampered by presbyopia than is the myope. The following table gives the mean accommodative power for ages ranging from 18 to 50 years (Duane):

Age	Diopters	Age	Diopters
18	11. 9	31	8. 6
19	11. 7	32	8. 3
20	11. 5	33	8. 0
21	11. 2	34	7. 7
22	10. 9	35	7. 3
23	10. 6	36	7. 1
24	10. 4	37	6. 8
25	10. 2	38	6. 5
26	9. 9	39	6. 2
27	9. 6	40	5. 9
28	9. 4	45	3. 7
29	9. 2	50	2. 0
30	8. 9		

Factors other than age may affect the power of accommodation. Local affections involving the eye itself, as oculomotor paralysis, irido-cyclitis, glaucoma, etc., will interfere with contraction of the ciliary muscle. Occasionally, a ciliary spasm may be encountered and in such an instance there may be induced an apparent myopia which will be misleading. In systemic affections resulting in general debility, particularly diabetes, also influenza and malaria, there may be a temporary reduction in accommodative power greater than should be expected for the age group of the individual. The action of drugs, especially atropine, should be borne constantly in mind, as an apparent premature presbyopia, or sudden reduction in visual acuity of a young, moderately hyperopic patient may be found to be due to the internal use of belladonna for some gastro-intestinal ailment or even due to the continued use of an ointment containing belladonna in the treatment of hemorrhoids. Drugs having a cycloplegic action are in particular atropine, homatropine, cocain, and scopolamine. Occasionally an examiner may determine that an applicant for enlistment has attempted to conceal his real age, by comparing his amplitude of accommodation with the mean for his age group, after taking into consideration errors of refraction and other conditions.

124. Determining accommodative power.—This test is performed with a card bearing letters subtending angles of 5 minutes

at approximately 620 millimeters and requiring 1.6 diopters of accommodation to focus them correctly. This test differs from the Jaeger test in that the card is read at varying distances while the Jaeger is read at a given distance and the size of the letters employed is varied when necessary.

The accommodation card is mounted upon a slide which can be moved along a rule; the Prince rule, or a modification of the same, is generally employed. The rule is calibrated in diopters and in millimeters.

Accommodation is measured from the anterior focus of the eye, which is, roughly, 11.5 millimeters in front of the cornea. Using a millimeter rule, a pencil mark is made in each side of the examinee's nose 11.5 millimeters in front of the right and left cornea, respectively. In measuring the accommodation of the right eye, the flat side of the Prince rule is laid against the right side of the examinee's nose, with the end of the rule at the pencil mark. The rule is held horizontally and extends directly to the front, edge up. The card of test letters is held not more than 5 centimeters in front of the examinee's right eye. His left is screened from sight of the letters by the flat side of the rule. The card of test letters is now carried slowly away from the eye and the examinee instructed to begin reading the letters aloud as soon as they become legible. The card is halted the instant he begins to read the letters correctly, and the point on the rule opposite the card is read off in diopters. This is the measurement of the greatest amount of accommodation that can be called into service with his right eye. To test the left eye the rule is changed to the left side of the nose and the above procedure is repeated.

125. Calculating accommodation in diopters.—The Prince and Thorne accommodation rules are calibrated in diopters and the amount of accommodation exerted at any given distance my be read off the scale. However, any centimeter or inch rule may be employed and the accommodative power calculated.

As previously stated, an emmetropic eye fixing an object at 6 meters does not accommodate, but accommodation is resorted to for all objects nearer than 6 meters. To fix an object located at 1 meter (40 inches), 1 diopter of accommodative power must be exerted as it requires 1 diopter of refraction to focus parallel rays of light this distance. Rays of light from an object at 1 meter are divergent and the emergent rays from an emmetropic eye are parallel, and the addition of 1 diopter of refraction will render the divergent rays parallel when they enter the eye and will focus the emergent parallel rays at 1 meter where the object is located. An object located at 50 centimeters (20

inches), 2 diopters of refraction are required, as it requires 2 diopters to render divergent rays of light from 50 centimeters parallel when they enter the eye and to focus the emergent parallel rays at the same distance. If an object is located at 33 centimeters, 3 diopters of refraction are required to focus it. Assuming an individual reads clearly at 12 centimenters, then to determine the number of diopters of accommodative power he is exerting, 100 centimeters is divided by 12 centimeters, which gives—

$$\frac{100}{12} = 8.33 \text{ diopters}$$

Again, letters are read clearly at 8 centimeters. Therefore—

$$\frac{100}{8} = 12.5 \text{ diopters of accommodation}$$

If desired, inches may be employed, in which case 40 inches is used as the basis of calculation. Thus, letters are read clearly at 4 inches, then—

$$\frac{40}{4} = 10 \text{ diopters of accommodation}$$

The amplitude of accommodation may be estimated by using spherical concave lenses before the eye, beginning with weaker lenses and replacing each with the next stronger until the examinee's visual acuity has dropped below his normal. For example, one who has an acuity of 20/20 and can still read 20/20 with a minus 6 sphere but cannot with a minus 6.50 sphere, has an amplitude of accommodation of 6 diopters provided he is emmetropic. If he is hyperopic his correction must be added to the strongest lens with which he has normal vision. If he is myopic his correction must be subtracted.

126. Near vision.—The object of the test for near vision is to determine whether or not the individual can call into use 3 diopters of accommodation, and the Jaeger test card is commonly employed for this purpose. The Jaeger card is prepared with six series of words. The first series should be read by the normal eye at a distance not greater than 37 centimeters; the second at 50 centimeters; the third at 62 centimeters, etc. The card is held before the examinee at a distance of 33 centimeters and he is directed to read the first series. If he does so, his near vision is recorded as J-1-13″, indicating that he reads Jaeger No. 1 at 13 inches or 33 centimeters. If number two is the smallest that he can read easily, his near vision is recorded as J-2-13″, indicating that he reads Jaeger No. 2 at 33 centimeters, or or 13 inches. The smallest type that he can read at 33 centimeters is the basis of his near vision. The normal eye should read J-1-13″. If this cannot be done it indicates that his near vision is defective, and if distant vision is normal, he is presbyopic.

J. 1 (Sn. 0.5). 50 cm.

As she spoke, Moses came slowly on foot, and sweating under the deal box which he had strapt round his shoulders like a pedlar. "Welcome, welcome, Moses! well, my boy, what have you brought us from the fair?"—"I have brought you myself," cried Moses, with a sly look, and resting the box on the dresser. "Ay, Moses," cried my wife, "that we

J. 2 (Sn. 0.6). 60 cm.

five shillings and twopence is no bad day's work. Come, let us have it then."—"I have brought back no money," cried Moses again. "I have laid it all out in a bargain, and here it is," pulling out a bundle from his breast: "here they are; a gross of green spectacles, with silver rims and

J. 4 (Sn. 0.8). 80 cm.

mother," cried the boy, "why won't you listen to reason? I had them a dead bargain, or I should not have brought them. The silver rims alone will sell for double the money."—"A fig for the silver rims," cried my wife, in a passion. "I dare

J. 6 (Sn. 1). 1 m.

the rims, for they are not worth sixpence; for I perceive they are only copper varnished over."—"What!" cried my wife, "not silver! the rims not silver?"—"No," cried I, "no more silver

J. 8 (Sn. 1.25). 1.25 m

with copper rims and shagreen cases? A murrain take such trumpery! The blockhead has been imposed upon, and should have known his company better."—"There,

J. 10 (Sn. 1.5). 1.5 m.

the idiot!" returned she, "to bring me such stuff: if I had them I would throw them in the fire."—"There again you are wrong, my dear," cried I,

J. 12 (Sn. 1.75). 1.75 m.

By this time the unfortunate Moses was undeceived. He now saw that he had

J. 14 (Sn. 2.25). 2.25 m

asked the circumstances of his deception. He sold the horse, it

Jaeger test types, with approximate Snellen equivalents and the most remote distances at which each should be read with average normal vision.

FIGURE 22.—Test types for near vision.

SECTION XVII

INSPECTION OF THE EYE

127. General.—*a. Equipment.*—The inspection of the eye, or the external examination, is altogether objective. In this part of the examination a great deal can be observed with the unaided eye, but for detailed examination some artificial assistance will be required.

b. Structures.—The examiner should adopt a definite routine in the inspection of the eye, which he may work out to his best advantage considering the equipment he has available. It is suggested that the following structures be inspected in turn, although the steps or phases of the examination may be varied as a matter of convenience.

(1) Eyelids.
(2) Lacrimal apparatus.
(3) Conjunctiva.
(4) Globe as a whole.
(5) Cornea.
(6) Sclera.
(7) Iris and anterior chamber.
(8) Lens and vitreous.

c. History.—While proceeding with the inspection of the eye the examiner should obtain a history of any ocular defect, affection, or injury.

128. Focal or oblique illumination.—Focal or oblique illumination affords the opportunity of a detailed examination with magnification of the structures examined, and yet requires only the simplest of equipment. It can be carried out best in a darkened room with the examinee seated near a lamp located about 2 feet above and to one side of his head. A strong convex spherical lens is held between the examinee and the source of illumination in such a position that the divergent rays are brought to a focus or concentrated on the structure being examined. This causes an intense

illumination of the cornea, iris, etc., and may enable the examiner to uncover some abnormality with his unaided eye. However, a greatly enlarged image of the structure under observation may be obtained by the use of a second strong convex lens being held by the other hand between the eye of the examiner and the eye being examined, and through which an enlarged image may be seen. It is advisable that the eye of the observer be near the second lens, which may be moved back and forth until a sharply defined image of the part under examination is obtained. To be adept in the handling of the two lenses requires some practice, and it is advisable that the student repeatedly attempt the procedure with a normal eye until it is mastered. In addition, such practice will enable him to be familiar with the appearance of normal structures, which is essential before attempting to recognize abnormalities.

129. Binocular loupe.—The binocular loupe, such as the Beebe in particular, has a distinct advantage over the use of a single magnifying lens, in that a true stereoscopic effect is obtained in addition to magnification. This aids materially in appreciating depth. Furthermore, the binocular loupe is worn as spectacles and leaves the hands free to manipulate the lids, etc., during the examination.

130. Hand slit-lamp.—*a. Method.*—The hand slit-lamp affords an opportunity every examiner should take advantage of, if he has one available, for the examination of the cornea, anterior chamber, iris, and lens. It is a simple, compact little instrument that is an improvement over oblique illumination. From its aperture there is projected a beam of light, the dimensions of which may be varied as desired, which "cuts" sections through the transparent structures. These sections are examined through a system of magnifying lenses attached at an angle to the head of the instrument, or through the binocular loupe. As with oblique illumination, the hand slit-lamp gives better results when used in a dark room.

b. Microscopy.—Actual microscopy of the living eye has been made possible by the use of the slit-lamp of Gullstrand in conjunction with the binocular corneal microscope. In addition to the fact that such an instrument is rarely available, the technique of its method of use is so complicated that a description of the instrument is hardly justifiable.

131. Examination of eyelids.—Even a casual inspection will reveal a malposition, distortion, enlargement, or contracture involving the lids, and in making such an inspection the examiner should be particularly observant as to their motility, which may be altered, as in ptosis and facial paralysis. The lid margins should be noted as to the existence of entropion, ectropion, trichiasis, blepharitis, cica-

trices, chalazia, and sties; the history or presence of sties may be symptomatic of errors of refraction. Deformities of the lids that appear at a glance to be insignificant may be actually of a serious

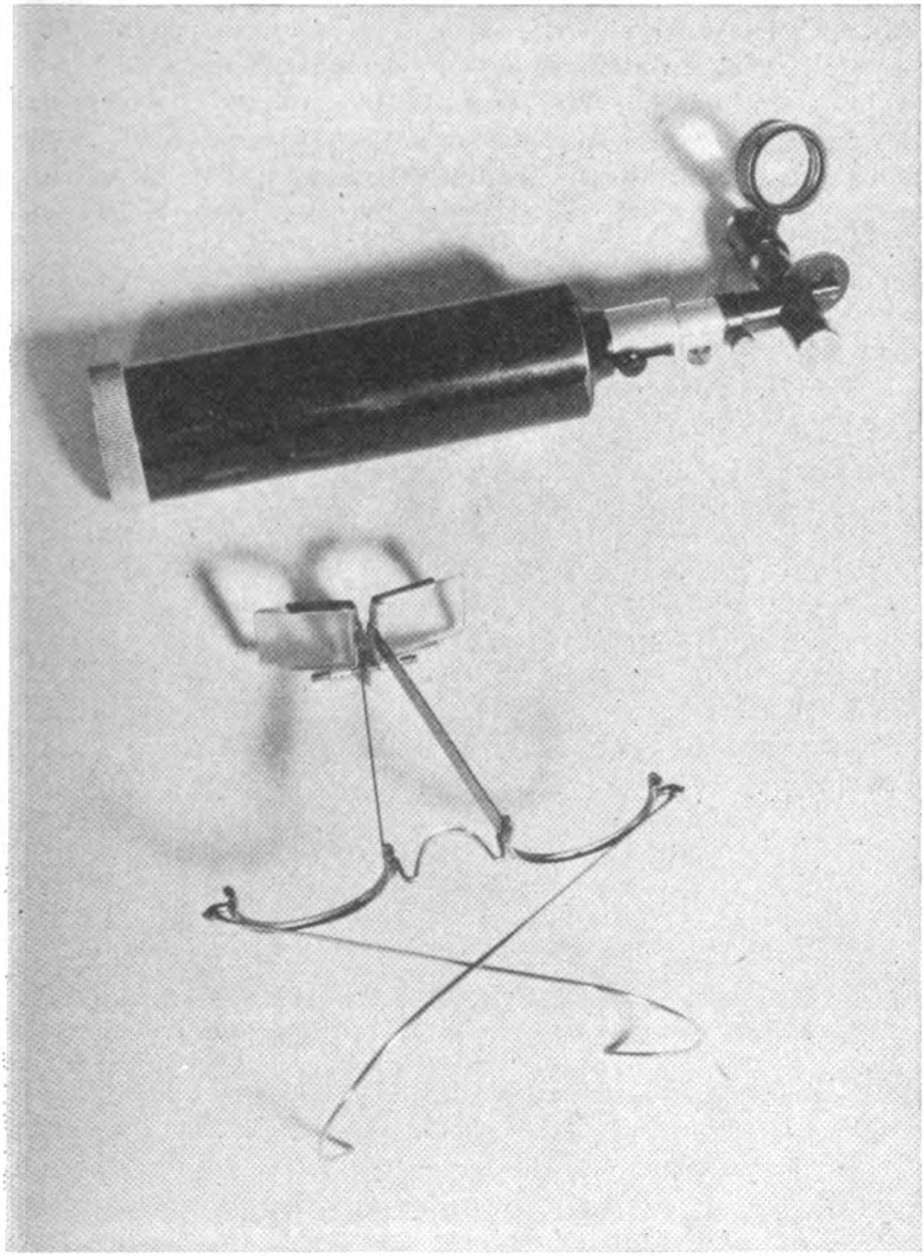


FIGURE 23.—Bausch and Lomb hand slit-lamp (above) and Beebe binocular loupe (below).

nature and the danger of corneal irritation and interference with proper function of the lacrimal apparatus should be borne in mind.

132. Lacrimal apparatus.—*a.* The lacrimal apparatus may be

inspected along with the examination of the lids and of the conjunctiva. Affections involving the secretory portion are unusual but when enlargements are present, if not seen readily, they may be palpated. These enlargements may account for a defect in the movements of the globe. The excretory portion may show many defects, either congenital or resulting from disease or trauma. The puncta may be so displaced that normal drainage from the conjunctival sac is impossible, and such a condition may cause an epiphora with a chain of complications, interference with normal visual acuity, blepharitis, or eczema of the lower lid. Where there exists a doubt as to the patency

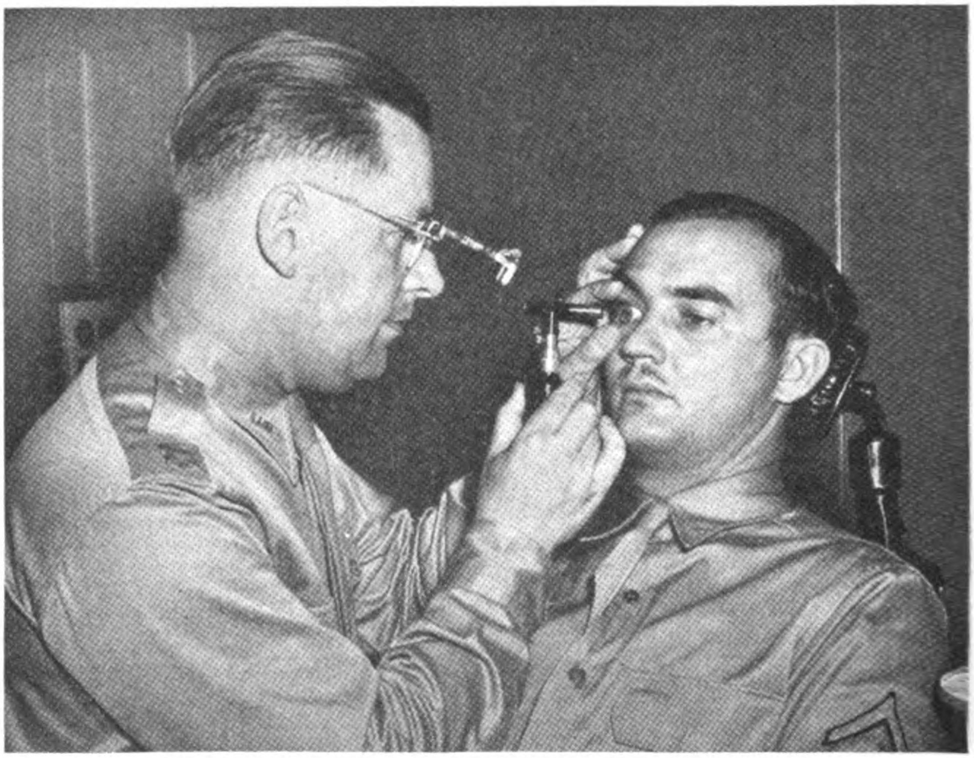


FIGURE 24.—Use of Beebe binocular loupe in conjunction with hand slit-lamp.

of the canaliculi, the lacrimal sac or the naso-lacrimal duct, a lacrimal syringe may be used (argyrol should not be used due to possibility of argyrosis). Acute and chronic dacryocystitis are conditions that, as a rule, are recognized without difficulty, but any enlargement in the location of the sac, or pain on pressure in this locality, should arouse some suspicion on the examiner's part. Pressure over the sac causes a back flow through the canaliculi, and where the secretion is of a mucoid or purulent nature it is significant of dacryocystitis.

b. Other abnormalities may be noted at this point before proceeding with a detailed examination of the globe itself, particularly

the position of the globe within the orbit, enophthalmus, exophthalmus, and also abnormal position of the visual axes, although in this connection the angle kappa must be borne in mind. When positive, the examinee will have the appearance of divergent squint, and when negative a convergent squint will be simulated. Positive kappa angle is more frequently found associated with hyperopia and a negative kappa angle with myopia.

c. Next the examiner's attention should be directed to an investigation of the palpebral portions of the conjunctiva and the fornices. The lower palpebral conjunctiva and the lower fornix are exposed easily by exerting slight pressure with downward traction on the skin of the lower lid and at the same time directing the examinee to look upward. The upper palpebral portion and fornix are exposed by everting the upper lid. Without some practice this may occasion the examiner difficulty. Probably the easiest as well as the simplest method is as follows: The examiner faces the examinee and the latter looks downward. With the right hand the left lid is everted. The right index finger is placed horizontally over the closed left lid and the cilia gently grasped between the index finger and thumb. Slight traction is made toward the temporal side at the same time the tip of the index finger is a point around which the lid can be vertically rotated. The tarsus is everted, exposing the palpebral conjunctiva. The left hand of the examiner is used to evert the examinee's right upper lid. This enables the examiner to use only one hand but does not expose the superior fornix thoroughly, and is a difficult procedure where the eyes are not prominent. Another method, which may be found to be more satisfactory, is to place a blunt probe (or eustachian catheter) at the upper edge of the superior tarsus with the lid closed and the examinee looking downward. The lashes are grasped between the thumb and index finger and the lid pulled away from the globe. The end of the probe is depressed as the lid is everted. By moving the probe laterally back and forth while the examinee looks downward the whole of the superior fornix may be exposed.

d. In examining the tarsal conjunctiva attention must be paid to scarring, as from trachoma, evidence of inflammatory conditions, follicles, etc. Especially any alteration should be noted in the character of the secretion in the conjunctival sac.

e. The bulbar conjunctiva may be examined in its entirety without eversion of the lids by widely separating them and at the same time directing the examinee to look up and then down. Any abnormality should be noted, particularly hyperemia. In this connection, the

differential points of conjunctival and ciliary injection may be mentioned.

Conjunctival injection	Ciliary injection
(1) Derived from posterior conjunctival vessels.	(1) Derived from anterior ciliary vessels.
(2) Accompanies diseases of the conjunctiva.	(2) Accompanies diseases of the cornea, iris, and ciliary body.
(3) More or less muco-purulent or purulent discharge.	(3) Often lacrymation, but no conjunctival discharge.
(4) Most marked in fornix conjunctivae.	(4) Most marked immediately around the cornea; hence called "circumcorneal."
(5) Fades as it approaches the cornea	(5) Fades toward fornix.
(6) Bright, brick-red color	(6) Pink or lilac color.
(7) Composed of a network of coarse tortuous vessels, anastomosing freely, and placed superficially, so that the meshes are easily recognized.	(7) Composed of small, straight vessels, placed deeply, so that individual vessels cannot be recognized easily, but are seen indistinctly as fine, straight lines radiating from the cornea.

f. The presence of a pterygium should be noted and, if present, a conclusion reached as to whether it is progressive or nonprogressive, the former being more vascular with the head distinctly elevated above the level of the cornea. True and false pterygia should be differentiated, and where a pterygium exists the encroachment, in millimeters, on the cornea should be noted. Pinguecula must be differentiated from pterygia, the former being a triangular patch of yellowish, thickened conjunctiva, base toward the limbus, more frequently located on the nasal side, but not encroaching on the cornea, as does the pterygium, nor is it so vascular.

g. Other abnormal conditions of the conjunctiva to be looked for are concretions, ecchymosis, chemosis, xerosis, argyrosis, cysts, and tumors.

133. Inspection of sclera.—*a*. Inspection of the sclera may reveal evidences of episcleritis or scleritis (elevated and discolored nodules) or protrusions (staphylomata) resulting from a localized thinning of scleral tissue from inflammatory changes.

b. The normal cornea is quite transparent, avascular, and shows bright, sharply defined reflexes on its convex surface. Wherever there is an abrasion, or facet, or depression, the reflex of an object a few feet away, as, for example, a window, will appear somewhat dis-

torted. Opacities of the cornea may be so slight that some magnification will be required for their detection. A dense and entirely opaque area is ordinarily designated as a leucoma; one having a more translucent appearance, as of ground glass, a macula; and one that amounts to a faint clouding only, a nebula. The position of an opacity is of significance. A large, centrally located nebula actually interferes with vision more than a smaller, although quite dense

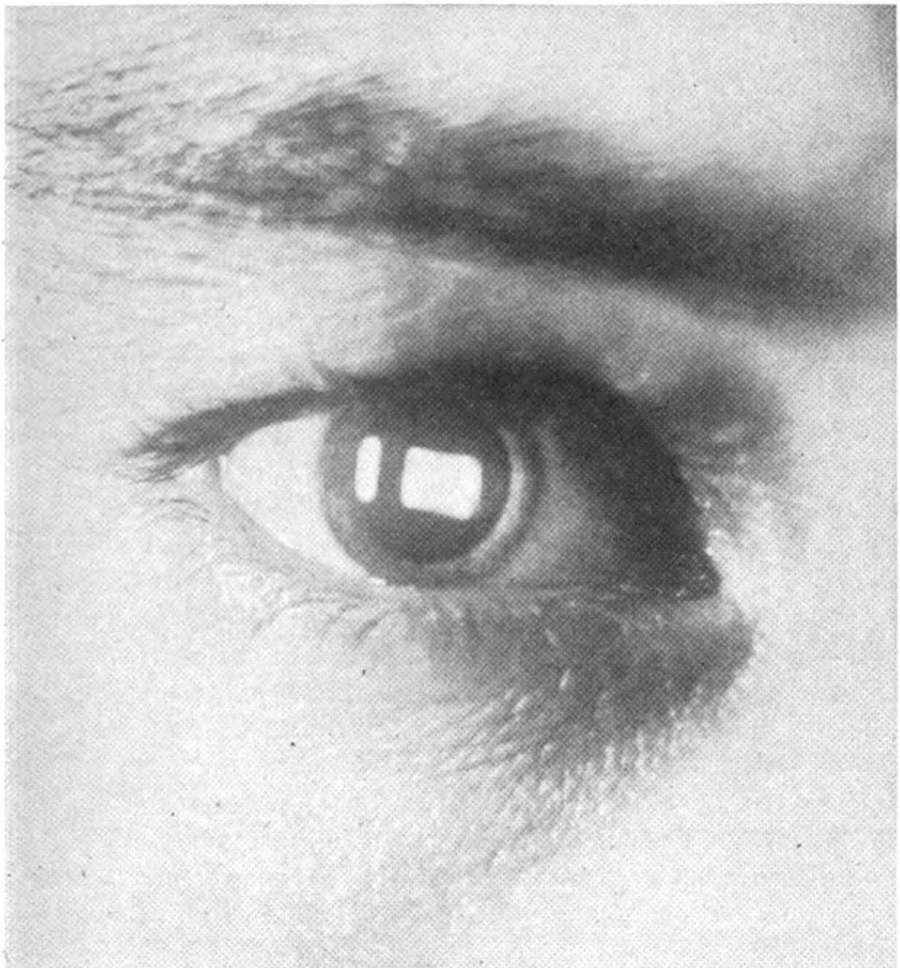


FIGURE 25.—Section made by slit-lamp through cornea and lens as seen through the loupe.

leucoma located near the periphery. Where a cicatrix of the cornea exists the normal curvature of the cornea may be interfered with over an area larger than that of the opacity itself, causing an irregular astigmatism.

c. In the examination of the cornea, focal illumination is essential, and the value of the hand slit-lamp, either with the monocular or binocular loupe, cannot be overemphasized. The student is encour-

aged to practice at every opportunity, in order to familiarize himself with the use of this instrument. In particular he should learn to focus the beam of light so that a sharply defined corneal parallelopiped is obtained; then he should learn by experience how to avoid annoying corneal reflexes.

d. The student should first devote considerable time to the examination of the normal cornea before attempting to diagnose pathological conditions. By the slit-lamp many abnormalities may be determined much more readily than otherwise; for example, thickening or thinning, opacities, superficial or deep, vascularity (superficial in pannus, deep in interstitial keratitis), degenerative changes, deposits on the posterior surface of the cornea (keratic precipitates), and anterior synechiae.

e. The electric ophthalmoscope, with a strong convex lens rotated in the aperture, is of value in the examination of the cornea. Opacities observed in this manner appear much darker than they actually are due to the fact that they are in part illuminated from behind, and hence in a manner cast shadows of themselves.

134. Anterior chamber and iris.—*a. Anterior chamber.*—The anterior chamber may be observed in conjunction with the examination of the cornea and the iris. Normally, it is approximately 2.5 millimeters deep. Its depth is estimated by the position of the iris which, when viewed through the strongly convex cornea, appears enlarged and further forward than it actually is. Binocular vision, as with the Beebe loupe, is a valuable aid in estimating the depth of the anterior chamber. Again, the value of the hand slit-lamp may be emphasized. The normal aqueous of the anterior chamber is a colorless and perfectly transparent fluid, and where a beam of light can be seen in the anterior chamber, when the slit-lamp is used, it is definitely indicative of an alteration in the character of the aqueous, as may result from an irido-cyclitis. A comparison may be made to a narrow beam of light entering a darkened smoke-filled room. The anterior chamber may contain blood (hyphaema) or pus (hypopyon).

b. Iris.—In examining the iris attention is paid to the color and definition of the lace-like pattern. A comparison should be made with the fellow eye. Normally, the crypts are clearly defined and the surface of the iris appears rather brilliant, regardless of disposition of pigment. At the pupillary margin there is a definite continuous ring of somewhat nodular dark brown pigmented epithelium, the anterior termination of the pars iridica retinae. Immediately around the pupillary margin and concentric with it, are circular ridges indicating the location of sphincter fibers of the iris.

A "muddy-colored" iris with an apparent diminution in size of the crypts associated with an irregularly contracted pupil, sluggish in reaction, is suggestive of iritis. Further, a break in the continuity of the epithelial ring of the pupillary margin should arouse one's suspicion as to the history of iritis—occasionally the detached portion of epithelium may be found adherent to the anterior capsule of the lens, indicating the site of a previous posterior synechiae. Particular attention should be paid to the presence of synechiae. Posterior synechiae are definitely indicative of a past or present iritis, the etiology of which is of importance (possibility of rheumatc or luetic history). Congenital anomalies of the iris are not infrequently encountered, especially persistent pupillary membrane. This may vary from a single delicate thread-like structure hanging across the pupil, or below it, to a fairly heavy band. The latter, however, is uncommon. This abnormality can be differentiated from post-inflammatory lesions by the fact that the strand of tissue in persistent pupillary membrane is attached to the iris definitely outside the margin of the pupil. Furthermore, persistent pupillary membrane does not, as a rule, interfere with dilatation when a mydriatic is used.

135. Examination of pupils.—*a.* In the examination of the pupils the examinee should be seated facing the light and each of the two pupils should receive an equal amount of illumination. Both eyes should be shaded from the light by the examiner's hands; one hand is removed, exposing the eye to the light and the contraction of the pupil noted (direct reaction). The same is done with the fellow eye. Next observe the pupil of the eye shaded from the light when the other eye is exposed (consensual reaction), the procedure being repeated with the opposite eye. The reaction to accommodation is noted by first directing the examinee to fix upon an object in the distance, then suddenly to fix upon a point about 10 centimeters away. As accommodation occurs the normal pupil will contract.

b. In the condition commonly referred to as the Argyll Robertson pupil the pupils usually are contracted appreciably; they do not react to light but do react to accommodation. This is a symptom commonly found in luetic diseases of the central nervous system.

c. There is assumed to be located in the floor of the aqueduct of Sylvius near the nuclei of the third cranial nerves two nuclei or centers, one on each side, known as the photomotor nuclei. These nuclei are the cerebral centers which govern contraction of the pupil when the retina is stimulated by light.

d. The theory is that there are two reflex arcs which control pupillary contraction and are independent of each other. One of these arcs

causes contraction of the pupil when accommodation occurs, while the other causes it to contract when the retina is stimulated by light.

(1) The reflex arc governing pupillary contraction during accommodation is formed by nerve fibers passing from the retina to the circular muscle fibers of the iris by way of the optic nerve and tract, the ganglion of the third cranial nerve, and the ciliary ganglion.

(2) The reflex arc governing contraction of the pupil following stimulation of the retina by light is found by nerve fibers passing from the retina to the circular muscle fibers of the iris by way of the optic nerve and tract, the photomotor nucleus, and the ciliary ganglion.

This system of two independent reflex arcs explains the Argyll Robertson phenomenon, that is, the pupil that reacts to accommodation but not to light. A lesion involving the photomotor nucleus breaks the reflex arc governing light stimulation and the pupil fails to react. The nucleus of the third cranial nerve not being involved, the reflex arc remains intact and consequently the pupil will react to accommodation.

Association fibers are supplied from the primary optic ganglia to the ganglia of the fourth and sixth cranial nerves to control the superior oblique and the external rectus mucles.

e. Unusually large pupils may be indicative that a mydriatic has been used, either locally or possibly as an internal medication. In this instance there will be an associated diminution of accommodation power. Dilated pupils are also found in complete optic atrophy, in glaucoma (immobile and oval with axis vertical), cervical sympathetic irritation, and from trauma (iridoplegia).

f. Small pupils are frequently found with central nervous disease associated with the use of drugs, either locally as eserine or internally as morphine, or may be indicative of an old iritis.

g. The degree of contraction when the pupil is exposed to light is to be observed, as well as whether or not the contraction is well maintained. In retrobulbar neuritis, while the pupil reacts readily upon exposure to light, it may slowly dilate upon continued exposure to brilliant illumination.

136. Lens.—*a. Examination.*—In the examination of the lens some artificial aid is necessary. Again the hand slit-lamp will be found to be of great value. Furthermore, the lens in its entirety cannot be inspected thoroughly through a contracted pupil. Consequently, the use of a mydriatic will be found to be of considerable benefit. Where a transient dilatation of the pupil is desired without a pronounced cycloplegia, euphthalmine in a 4-percent aqueous solution will ordinarily be effective, although the examiner will find as a rule that euphthalmine is much more effective upon blondes than upon brunettes. The same is true as regards homatropine. In many

instances even the repeated instillation of euphthalmine in the eye of the Negro will have only a barely appreciably effect in dilating the pupil. In the examination of applicants for flying training, a cycloplegic is used (prior to retinoscopy), and the examination of the lens may be postponed until the ophthalmoscopic examination is made.

b. Opacities.—Opacities in the lens substance or upon either capsule appear both with oblique examination and with the slit-lamp as grayish or yellowish areas. With the ophthalmoscope they will appear very much darker, and for this reason may be detected more readily. In inspecting the crystalline lens a strong convex lens is rotated before the aperture of the ophthalmoscope. This affords considerable magnification. The pupillary margin is then brought into sharp focus and, as the pupillary margin is in direct contact with the anterior capsule of the lens, this focus must be that for the anterior surface of the lens. The hand slit-lamp with the binocular loupe is especially useful in locating the position of opacities of the lens, that is, whether on the anterior capsule within the lens substance or on the posterior capsule, as the case may be. The hand slit-lamp does not replace the ophthalmoscope in the examination of the lens, but it is a very desirable adjunct to it. In the inspection of the lens, using the hand slit-lamp or the ophthalmoscope, particular attention should be paid to the periphery of the lens. Iritis often leaves its indelible mark on the anterior capsule as detached portions of the pars iridica retinae, dark brown pigmented patches firmly adherent to the capsule. Rarely there may be seen remnants of persistent pupillary membrane occurring as minute, usually stallate, pigmented patches on the anterior capsule. The latter, of no significance, must be differentiated from evidences of an old iritis.

Since the lens is an isolated portion of epithelial structure it is subject to degenerative rather than inflammatory changes. Such changes result eventually in opacities (cataract). The student is advised to review, in any text, the objective findings with the varieties of cataract.

137. Opacities of vitreous.—*a. Means of observation.*—Opacities of the vitreous may be observed by means of the ophthalmoscope, and with the slit-lamp when they are located anterior to the equator. With the ophthalmoscope they appear as shadows; with the slit-lamp they show in their natural appearance.

b. Method.—The examinee may be directed to look from the right to the left suddenly, or his temporal region may be jarred by a gentle blow, which may bring into view floating opacities in the vitreous. When opacities in the vitreous are found, and they are quite motile, the conclusion may be reached that the vitreous is abnormally fluid in character. In using the ophthalmoscope, after inspecting the lens sub-

stance, the convex spherical strength of the lenses should be gradually reduced, thus bringing into focus any structure that may exist between the posterior lens capsule and the retina.

c. Palpation of globe.—Finally, the globe should be palpated and an estimate of intra-ocular tension made. The examiner stands facing the

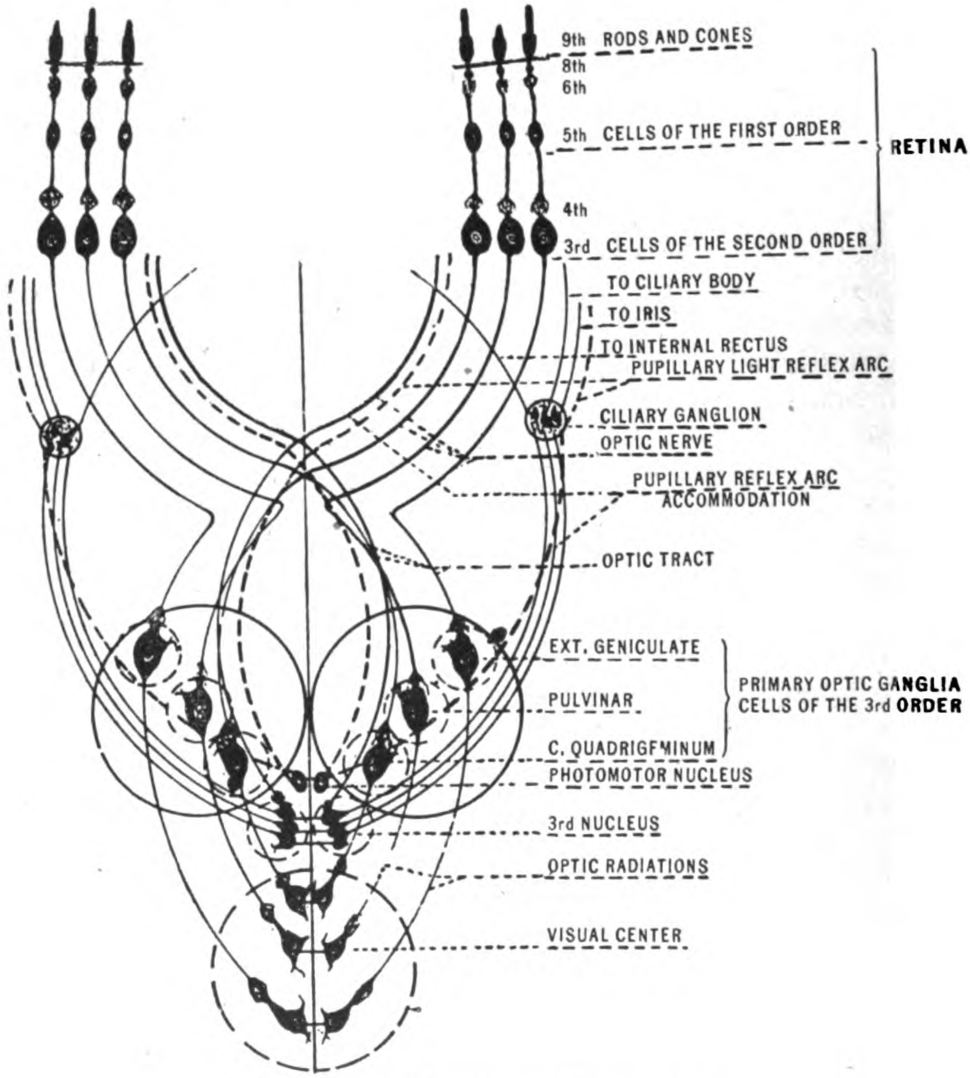


FIGURE 26.—Visual pathways (diagrammatic).

examinee who is directed to look downward. The examiner places the index finger of each hand upon the skin of the upper lid immediately beneath the aperture of the orbit and above the superior tarsal plate. One finger is held still, maintaining a steady pressure upon the globe through the lid, and with the other gentle indentations are made upon the globe pressing downward. In the meantime the examiner

concentrates his attention upon the impression which is conveyed to the finger which remains stationary. The student must practice this maneuver on many normal eyes, and thus obtain a mental estimate of what may be considered as normal tension, recorded as *Tn.* In cases of extreme increase in intra-ocular tension, as in absolute glaucoma, where the globe is palpated as having a strong or boardlike hardness, the tension may be recorded as *T* plus 3. Various estimates may be made, in comparison with palpation of the normal globe and findings, as *T* plus 1, or *T* plus 2, recorded. In a similar manner diminished tension may be recorded as *T*-1, *T*-2, *T*-3, etc. Accurate estimations

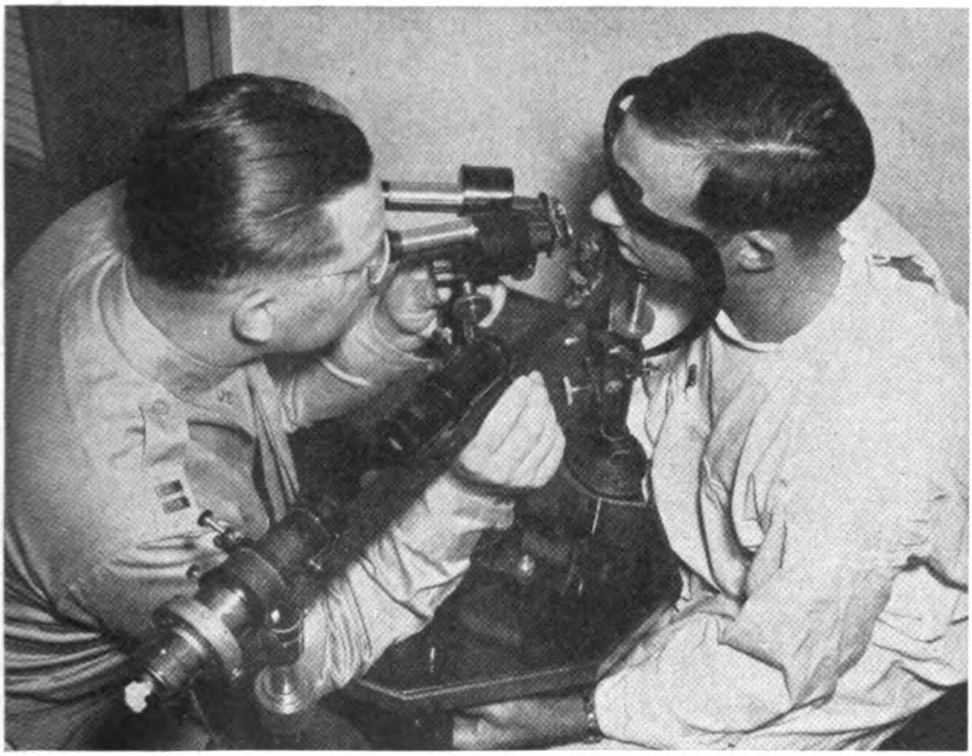


FIGURE 27.—Slit-lamp study of anterior segment of eye.

require considerable experience and the student is encouraged to practice making an estimate of intra-ocular tension at every opportunity. He always has his own eyes to palpate.

d. Tonometer.—The intra-ocular tension may be estimated more accurately by the use of a tonometer, which records the approximate intra-ocular tension in millimeters of mercury. The use of such an instrument, which presses against the corneal curvature, must be preceded by a local anaesthetic, as a depth of indentation of the cornea is used as an indication of the intra-ocular tension. There are several tonometers made, and each has its own characteristic as to interpreta-

tion of findings, and each has its own so-called range of normalcy. It is advisable that, except in cases of quite obvious marked increase in intra-ocular tension, repeated readings be taken before arriving at a conclusion.

e. Normal tension.—The normal intra-ocular tension is about 25 millimeters of mercury above atmospheric pressure, and this pressure is probably higher than that developed inside any other organ in the human body. It must be remembered that the tonometer, as used clinically, really measures the tension of the ocular coats, rather than the actual intra-ocular tension.

138. Nystagmus.—*a. Description.*—In the inspection of the eye nystagmus should be noted when present. By nystagmus is meant rapid oscillatory involuntary movements of the globe independent of the normal ocular movements, which are not affected. These movements are more frequently lateral but may be vertical or rotary, or even mixed. The condition is usually bilateral, but one eye may be more markedly affected than the other.

b. Source.—Nystagmus may be congenital or acquired. When congenital it is associated frequently with other stigmata, as albinism and total color-blindness. The acquired form in adults may occur with disease of the cerebellum and vestibular tracts, Friedreich's ataxia, disseminated sclerosis, and affections involving the semicircular canals. It may also occur as an "occupation neurosis," the commonest type being coal miner's nystagmus.

c. Nystagmoid movements.—Nystagmoid movements, jerky and somewhat irregular in character, which are noted only at extreme limits of the normal ocular movements, are of no significance and must be differentiated from a true nystagmus. Such movements may be found in normal individuals and may be more accentuated with fatigue.

Section XVIII

COLOR VISION

139. General.—*a. Detection.*—Considerable embarrassment has been caused by the failure to detect and properly report color-blindness on the examination of applicants for commission, and for entrance to West Point. Examples of the difficulty that has been experienced may be cited. Two officers who were commissioned in the Medical Corps of the Regular Army with color vision reported as normal were found to be color-blind on their first annual physical examination. A number of flying cadets have been relieved from the Air Corps Training Center because of color-blindness, though in each single instance the color perception had been reported as normal on one or more previous examinations. Aside from the embarrassment which such an oversight causes the Medical Department, it is obvious that considerable unnecessary expense is incurred in ordering these officers to the school only to find that they are physically disqualified for flying. It is equally obvious that if this gross disqualifying defect can be so easily detected by one group of examiners, it could have been detected in the first instance with material advantage to the Government. During the years 1934 and 1935, 2,355 candidates have been examined for admission to West Point. Of this number 20, or 0.84 percent, were reported as color-blind. It is known that approximately 3½ percent of the male population are dangerously color-blind; hence there is every reason to believe that in this group some 62 cases of color-blindness are not accounted for. A few were detected on the preliminary examination and did not come up for final examination. It is known that the number thus eliminated is small, however, and the not infrequent discovery of color-blindness on casual examination after appointment leads to the disturbing conclusion that the great majority of the 62 cases were accepted as normal because of faulty methods of examination, or failure to evaluate correctly such defects as were detected. Moreover, in the reports of examination received in The Surgeon General's Office it is quite apparent from the entries in cases of defective color perception that many medical officers have a very vague or a completely erroneous conception of what color-blindness is and of the proper procedure for its detection. When one considers that the detection of this rather common defect is not more difficult than the ordinary refraction, there seems to be little excuse for the very poor showing made. It is obvious that more careful at-

tention to the details of the examination of the color perception will remove a cause of embarrassment to the Medical Department and will be to the material advantage of the Government.

b. Treatment of subject.—The subject is here treated from the practical standpoint, with a desire to limit the discussion to those features that may be usefully applied in the routine physical examination for the detection of this defect and to leave the more theoretical aspects to others who are better qualified to discuss them. It is proposed to discuss the nature of color-blindness, to classify the various types that may be found, to show why color-blindness disqualifies for commission in the Regular Army, to indicate the best procedures for the detection of the defect, and finally to supply a list of references for the convenience of those who wish to pursue this very interesting subject further.

c. Definition.—It is common knowledge that the color vision of certain persons differs from that of the normal. Such persons are called "color-blind," a very unfortunate term, for it implies that they are blind to all color, and that all such persons have the same color perception. Neither of these implications has any basis in fact. The color-blind may be understood to include all of those persons whose color vision is different from that of the normal, and whose perception of color is, in general, more limited. They may be divided at once into two classes—the congenital and the acquired. We will not consider acquired color-blindness, for this type is uncommon in the age groups with which we are concerned; moreover, in these cases the defective color vision results from a grave intoxication or is but a part—usually a minor part—of a serious ocular or neurological disorder.

d. Congenital color-blindness.—Congenital color-blindness is a developmental defect. It almost always affects both eyes. The other ocular functions are not affected. It is hereditary, and tends to be transmitted through the females, and to be manifest in the males. The condition cannot be corrected, or even improved, though the color-blind do learn to conceal the defect. They are frequently ignorant of the defect themselves, but even when they realize that their color vision is not as good as normal they tend to minimize it as color ignorance, poor shade discrimination, etc.

e. Occurrence.—It is estimated that about 80 percent of the population have normal color vision. Of the remaining 20 percent, a considerable proportion are the acquired color-blind. Congenital color-blindness of some degree occurs in from 8.5 percent to 10 percent of men and about 2 percent of women. Color-blindness of such degree as to be disqualifying in occupations requiring color discrimination occurs in approximately 3.5 percent of men and 0.7 percent of women. It is this 3.5 percent of the candidates for commission with whom we

are concerned. In examining applicants for flying training, effort must also be made to detect the milder grades of defect and to eliminate the entire group (8.5 percent to 10 percent) with subnormal color perception.

140. Physical basis of color vision.—*a. Retina.*—In addition to the inability to discriminate between light waves of varying lengths by the fovea or central portion of the retina, there are other factors which render color-blindness still more complicated.

(1) *Zones.*—If all the area of the retina were sensitive to color stimulation to an equal degree, the problem of color-blindness would be somewhat simplified. The retina, however, is divided into three zones, each having varying boundaries in different individuals and possessing varying degrees of color sensitivity and discrimination. These three zones are:

(*a*) Central zone (normal color vision).

(*b*) Medial zone, surrounding the central zone, in which only two colors, yellow and blue, are discernible. In the medial zone, reds appear as dark yellow or browns and long wave greens appear pale yellow, while bluish-greens are pale blue, and violet appears dark blue. Some greens intermediate between those that appear yellow and those that appear blue are practically colorless.

(*c*) Marginal zone, in which all color stimuli appear colorless and only form and shade are discernible.

(2) *Factors influencing zone.*—These three zones are not sharply separated, but grade into each other and the character of vision in any case is dependent not alone on exact position, wave length, saturation, and intensity of stimulus, but also upon its duration and motion and upon the amount of practice of the individual in discrimination and the degree of attention which is given the particular observation. External conditions of smoke, fog, dust, and contrast of light with other colors are also influential when the sources of light are at some distance from the observer.

(3) *Varying degree of color perception.*—Accurate and rapid discernment of color is limited to central vision (that is the condition in which the eye is directed immediately upon the light). In peripheral vision (when the medial and outer zones of the eye are used), while discrimination may under test conditions be more or less possible, colors are susceptible to confusion under many conditions. In the color-blind, the defect may occur in a restricted portion of the central area or it may cover the whole central area, so that there is no distinction between the central and medial portions of the retina in color perception, aside from the factor of greater practice in the use of one portion. The varying degree of color perception in the

various areas of the retina makes the division between the normal and the color-blind somewhat arbitrary. Added to this is the fact that brightness, saturation, and other conditions influencing color discrimination cause the degree of apparent color weakness to vary according to the conditions of the test.

(4) *Secondary criteria.*—The presence of secondary criteria of brightness and saturation make it possible for many color-blind people to pass tests of varying types. This is especially true of individuals who have had considerable practice in handling colored materials. The opposite is likewise true; the lack of practice of individuals in the discrimination of colors of low saturation confuses them on many of the tests.

b. Spectrum.—(1) *Description.*—A beam of sunlight passed through a prism is broken up and appears as the six colors of the solar spectrum. Light is due to the undulations of the luminiferous ether, the motion of the wave being perpendicular to the path of the ray. The longest rays perceived as color are at the extreme left end of the spectrum, the red end, and are estimated to have a vibration rate of 395 billions per second. At the extreme right end of the spectrum, that is, in the violet, the waves have a vibration rate of 763 billions per second. Between these two extremes, from left to right, the rays are arranged in a series with regularly increasing vibration rate and regularly decreasing wave length. Beyond the left or red end of the spectrum the rays (infra-red or heat rays) are not perceived by the light sense at all; likewise beyond the violet the ultraviolet or actinic rays give rise to no sensation of light or color. Hence, when one looks at the spectrum both of these regions are black.

(2) *Psychophysical series.*—This arrangement of the light waves constitutes a physical series. The sensations resulting from the action of this physical series on the sensory apparatus may be termed a psychophysical series. Given a sensory apparatus sufficiently sensitive, it is conceivable that each single ray would give rise to its corresponding sensation or color. The human visual apparatus, however, is not so sensitive. When the spectrum is viewed by the normal eye six bands of color are perceived. The spectrum may be represented as shown in figure 28.

(3) *Psychophysical units.*—The numerals represent the wave lengths that are commonly accepted as the dividing lines between the several colors. It will be noted from the distribution of these wave lengths that the bands of color are not of equal width. It is to be remembered also that the division between the colors is not a sharp and well defined one, as the lines in the figure indicate, but that each

color merges by fine gradations into the next one. Pure yellow and pure green, for example, are found at Y and G, respectively, and somewhere to the right of Y, say from a to b, the varying shades are properly described as shades of greenish yellow, while those occurring from b to c are yellowish green, and so on through the spectrum. Such areas are termed modified psychophysical units. There is a space extending on either side of Y, however, represented in our diagram by the space a to x, in which, although the waves differ slightly in length, no difference in color is perceived and the color from one part of this area is to the eye exactly the same as that from all other parts of the area. Such an area in the psychophysical series is termed an absolute psychophysical unit. By an approximate psychophysical unit is meant one that contains physical units which give sensations that are only nearly and not exactly alike; for example, the varying shades of yellow that make up the yellow band. An approximate

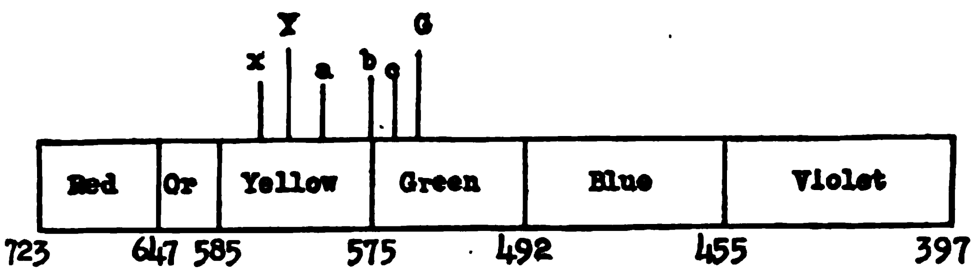


FIGURE 28.—Spectrum.

psychophysical unit, therefore, may contain a number of absolute psychophysical units which greatly resemble one another. When we keep in mind the fact that the total physical series with which we are dealing, namely, the solar spectrum, is incapable of being extended, it follows that if the size of some of the absolute units be increased the size of the approximate units must also be increased and that this increase must be at the expense of other units and may result in the complete obliteration of certain units. If in our diagram the blue and yellow bands are progressively expanded the green band between them will be correspondingly decreased and will finally be obliterated by the meeting of the blue and yellow. In an individual in whom such a change has occurred, light rays from the green band will give rise not to the sensation of green but to the sensation of blue or yellow, depending on which of these units has encroached on the part of the green band from which the rays come. Such an increase in one or more of the units of the psychophysical series, then, may result in any degree of encroachment on the remaining units. Instead of six colors, only five or four or three, or even less, are to be seen. Finally, there

is one other factor to be considered. If for any reason the sensory apparatus is not sensitive to the rays from any portion of the physical series, no color at all will be perceived in that area, that is, it will appear black. If this condition obtains at either end of the spectrum the spectrum is said to be shortened. If it is shortened at the red end, the red will appear black. If the shortening merely encroaches on the red band, only the corresponding shades of red will appear black, and the other shades will still be perceived as red. If, however, the shortening obliterates the red area, the ability to perceive red will be lost and all shades of red will appear as black. When this defect in the spectrum occurs, not as a shortening at the end but as a hiatus somewhere along its length, it is spoken of as a neutral band, and the color that should be seen in this area is replaced by black or gray, according to the intensity of the illumination. This then may be accepted for practical purposes as the mechanism by which the various types and degrees of "color-blindness" are produced, and all individuals may be classified as to color perception according to the number of psychophysical units that they perceive in the solar spectrum.

(4) *Maximum luminosity.*—Another factor that is operative in the production of the difference in sensation in the color-blind as compared to the normal is the shift in the point of maximum brightness. In the normal, with a brilliant spectrum the maximum brightness is in the yellow but with a feeble illumination it shifts to the green. As the light is diminished the red end becomes darker, while the green, blue, and violet appear relatively bright. In one type of color-blindness the maximum luminosity occurs in the green, as it tends to do in the normal with feeble illumination. We shall see later that relative luminosity is of great importance to the color-blind, since it is on this basis that they distinguish colors rather than by an actual difference in hue, as do the normal-sighted.

(5) *Units of perception.*—The normal-sighted individual distinguishes six distinct bands of color in the spectrum. If the intensity of the illumination is progressively diminished, however, the tendency is to a reduction of color perception so that the normal six unit or hexachromic is reduced to five units—pentachromic; then to four units—tetrachromic, etc. Finally, with further reduction of the light, all colors are lost and a condition of achromatism is reached in which the sensation is limited to the black, gray, and white series. This is the condition that obtains in many of the lower animals. Indeed, it is not improbable that the color vision of man was evolved by the reverse of this process. The animal that can perceive only light and shade can discriminate only in a rough way between varying intensities of the stimulus. It is apparent that the sense of sight must have de-

veloped first and then the sense of color. In the physical stimulus producing the sense of light there are two factors to be considered, the length of the wave and its amplitude; the greater the amplitude, the greater the stimulus. Therefore, the wave length of the physical stimulus is the physical basis of the sensation of color. When evolution has proceeded to the point where the organism is sensitive to rays, considerably above and below those which first caused a sensation of light, we have an eye that is sensitive to the greater part of the rays that form the visible spectrum; devoid, however, of any sense of color. No matter from what part of the spectrum the rays are taken, the only difference appreciated will be one of intensity. There now appears a fresh power of discrimination—the ability to discriminate between different wave lengths. Probably the wave lengths of greatest difference would be the first discriminated because of their very difference. It is presumed, then, that the first colors discerned were at opposite ends of the spectrum, namely, red and violet, provided the eye had become sensitive to this range. The individual would now see the spectrum a uniform gray of different degrees of luminosity, with a touch of red at one end and a tinge of violet at the other.

(6) *Trichromic spectrum.*—In the degree of color-blindness, just preceding total, the spectrum is seen in this way. The next stage in the evolution of the color sense was when the color receiving center had developed sufficiently to discriminate a third color, namely, green, which is in the center of the spectrum, the third point of greatest physiological difference. About 1.5 percent of men see the color spectrum in this way, namely, red, green, and violet. These are the so-called trichromic types. They describe the spectrum as consisting of red, red-green, green, green-violet, and violet. They do not see yellow and blue as distinct colors. They will declare that patches of greenish-yellow and orange-yellow are absolutely monochromatic. These cases often pass matching tests with ease.

(7) *Tetrachromic spectrum.*—In the next stage of evolution, four colors are seen in the spectrum, the fourth appearing at the fourth point of greatest physiological difference, namely, at the orange-yellow of the hexachromic, or six color people. These cases see red, yellow, green, and violet, but do not see blue as a definite color, classing this color with green.

(8) *Pentachromic spectrum.*—In the next stage of evolution, there appear those who see five colors in the spectrum; namely, red, yellow, green, blue, and violet. These are the pentachromic groups and these cases pass the tests in general use with ease. They cannot, however, see orange as a definite color.

(9) *Hexachromic spectrum.*—In the next stage of evolution, orange is recognized and we have the normal or hexachromic group; the yellow now being separated into two colors, namely, yellow and orange. In the last stage of evolution that we have reached are those who see seven colors in the spectrum, the additional one being indigo, which appears between the blue and the violet as a distinct color.

(10) *Classification of types of color vision.*—This concept of the evolutionary development of the color sense in a man very naturally lends itself to a classification of the various types of color vision. The normal-sighted may be termed as hexachromic; those with five colors, pentachromic; those who see four, tetrachromic; those who see three, trichromic; those who see two, dichromic; those who see one, monochromic; and those who see none, achromic, or totally color-blind.

(11) *Causes of congenital color-blindness.*—From what has been said, it is evident that the congenital type of color-blindness may be due to two causes: a reduction in the number of psychophysical units, or inability of the sensory apparatus to react to rays from certain portions of the spectrum. Further modification may be produced by displacement of the point of maximum luminosity.

(12) *Description of units.*—On the basis of the "unit" conception as outlined in the preceding pages a simple and workable classification of the types of color vision is easily made. It should be stated, parenthetically, that there are other classifications, some of which have features of value and which seem to be sound from the scientific standpoint. No attempt is made to pass on the relative validity of these conceptions. The unit classification is employed because of its simplicity, the ease of its application, and because it does seem to fill all requirements for the solution of the problem.

(*a*) *Seven unit; heptachromic.*—There are a few fortunate individuals (1 in several thousand) especially favored by nature, who have a seven-unit spectrum. The additional unit is described as an indigo and is distinct from the blue on the one hand and the violet on the other. The orange is also increased and there is a heightened perception throughout the whole spectrum. Hence they perceive differences of color that are not apparent to others and make facile discriminations that are accomplished with uncertainty and hesitation, or not at all, by their less fortunate brothers.

(*b*) *Six unit; hexachromic.*

1. Normal.—The normal six-unit spectrum, as described. This group comprises about 80 percent of the total population.

2. Shortened spectrum.—The shortening may occur at either the red or the violet end. If at the violet end of the spectrum, the defect is of little or no practical importance;

if at the red end, however, the individual may be in the dangerous color-blind group. If a red signal light or rocket is viewed at a distance or through the obscurity of a thick fog or smoke it may appear green to the six unit with shortened red. This is due to the fact that the red lights in common use contain not only red rays but green rays as well. Under conditions of obscurity the fog may blot out the few red rays that are capable of causing a sensation, while the green rays are perceived and give rise to the sensation green.

(*c*) *Five unit; pentachromic.*—The spectrum contains red, yellow, green, blue, and violet. The five unit is unable to see the orange band and the distinction between modified units is less sharp than in the normal person. The estimated incidence of this type of color perception is 7 to 10 percent.

(*d*) *Four unit; tetrachromic.*—Here the orange and the blue are not seen. The spectrum contains the red, yellow, green, and violet. Blue and green cannot be distinguished without direct comparison, and then only as slightly different shades of the same color. Since the green has encroached on the blue, blue is called green, but green is not called blue because the tetrachromic has no adequate conception of blue. About 3 percent of all persons are in this group. They are detected infrequently in the ordinary examination, any confusion that may be evident being ascribed to "color ignorance." The defect, however, is of little practical importance except in the Air Corps and the Veterinary Corps.

(*e*) *Three unit; trichromic.*—The spectrum is limited to the red, the green, and the violet. This type of defect is of a gross nature and gives rise to characteristic confusions in colors. Green is confused with brown (a dark shade of yellow or orange) because the green has encroached on the yellow area of the spectrum. He does not mistake red for green, however, unless the red end of the spectrum is shortened for him. About 1½ percent of the population are in this group. They are detected somewhat more frequently than the tetrachromic but when detected are often reported as "impaired color sense for green; not a true color-blindness" or some similar phrase.

(*f*) *Two unit; dichromic.*—This is the ordinary red-green type of color-blindness and is present in approximately 2 percent of persons examined. The dichromic spectrum is made up of two colors, dark yellow and blue, gradually shading into one another. Red, orange, yellow, and green, then, are seen as slightly different shades of the same color (yellow) while blue and violet are seen merely as shades of blue. Recent investigations indicate that the spectrum in

one type of dichromatism consists of green and blue; in these cases, therefore, red, orange, yellow, and green are perceived in terms of green; violet and blue in terms of blue. In addition to the reduction in the number of the approximate psychophysical units in dichromatism, there is also often found a displacement of the point of maximum luminosity from the yellow to the green, a shortening of the spectrum at either end, more commonly in the red, and the appearance of a neutral band in the middle of the green. This neutral band may widen until it occupies the entire spectrum and produces complete color-blindness. These variables give rise to certain main types of dichromatism, which embrace cases of all degrees of severity. These will be discussed more in detail a little later.

(*g*) *One unit; monochromic.*—The one unit or true monochromic with a spectrum that contains but a single color from end to end propably does not exist, since if any color at all is left in the spectrum there will be a short band in the extreme red and another in the ultimate violet. An individual with such a spectrum belongs for all practical purposes in the following class.

(*h*) *Color-blind; achromic.*—The total color-blind or achromic, happily, is very rare. A few cases are on record and have been carefully studied. The entire spectrum is devoid of any vestige of color. The more luminous portions appear gray, the less luminous dark gray or black. The external world is perceived in black and white and the intermediate grays. The fact that the totally color-blind have great aptitudes as engravers is but a sorry compensation for the tremendous esthetic deprivation.

This classification (adapted from Eldridge Green) is adequate for our purpose, since it embraces all of the main types of color vision that may be encountered and it indicates the great variation in degree that may be found within the several classes. Other writers divide the dichromats, or red-green blind, into two classes: those who have the yellow-blue spectrum with a neutral band of variable width centering in the green are called "deuteranopes" or green blind; those, some of whom are now believed to have a green-blue spectrum with a shortening at the red end, are termed "protanopes" or red blind. The tetrachromic, pentachromic, and the hexachromic with shortened spectrum are termed anomalous trichromates. The trichromics are sometimes included in this group, and sometimes are termed "tritanopes."

(13) *Dangerous color-blindness.*—It has been indicated that certain types of impaired color vision, that is, the pentachromic, are of little or no practical importance and are not readily detected by the ordinary methods of examination. Certain others, however, are of

serious consequence in any individual whose occupation requires accurate and rapid discrimination between colors under varying conditions. Individuals with these types of defective color perception are properly described as "the dangerous color-blind" and are disqualified for commission in all arms and services except the Corps of Chaplains. They are those with a color perception containing but three units or less, or those with a color perception containing more than three units who have the red end of the spectrum so shortened that the shortened red can be detected by the ordinary tests. Before we go on to a more detailed consideration of these dangerous types, there are certain features that are common to all types that should be mentioned.

(14) *Elementary facts.*—On investigating the subject of color perception one is impressed by the extraordinary degree of confusion that is found. This confusion seems to arise from two causes. First, the theories of color vision. The tendency has been to start with some special theory and so far as possible to make all observed facts fit the particular theory. The second cause of the confusion is due to the nature of the subject itself. In investigating color-blindness we are dealing not with ponderable realities of the external world but with sensations, that is, the effect produced in the consciousness of the individual by certain stimuli. The stimulus, the series of light waves that make up the solar spectrum, is constant and immutable; the sensation, the color excited by the action of these rays on the sensory apparatus, has no reality save in the consciousness of the observer and may vary greatly in different individuals. If two individuals look at a colored object and both call it green it is assumed that both have the same sensation. It is not known, and cannot be known, whether both have exactly the same sensation, or even that the sensations of the two remotely resemble one another. On the other hand, if one observer says that an object is red and another calls it orange, it cannot be assumed that their sensations are necessarily different. It may be a mere difference in nomenclature. The term "orange" denoting a color is not included in the vocabularies of many persons. They are content to refer to the shades of orange as red or yellow, yellowish-red, etc. Now consider the possibilities when an examinee selects a bright green and a bright red as perfect matches. It is known at once that the two look the same to him. The question arises as to whether he sees the green as red or the red as green, or whether he sees both red and green as some other color, yellow for example, or as devoid of color—gray. In examining for color-blindness it must be remembered that naming a color correctly does not necessarily mean that the examinee sees

the color correctly. Red to him may be merely a matter of luminosity and, although he uses the term glibly and in the main appropriately, he has never experienced red as a sensation and it is as impossible for us to tell him what we mean by red as it is for us to describe light to a person who has been blind from birth and has never experienced light. If these elementary facts are not borne in mind, confusion is the result and erroneous conclusions are almost inevitable. Thus a simple dichromat may be called "color-blind to brown, weak for green" on one occasion and "color-blind for red and blue" on another and on reexamination be reported "color-ignorant, not a true color-blindness."

(15) *Color-blind individual*.—The color-blind individual is actually blind to color only in those portions of the spectrum, usually limited in extent, where a neutral band occurs. These neutral colorless areas occur at either end or centered in the green. The remainder of the spectrum contains color, though the number of distinct units is reduced. At least two units are preserved. If the spectrum is shortened, the point of maximum luminosity is shifted away from the shortened end. With such an equipment he is able to see two of the six primary colors almost as well as the normal. Under ordinary conditions he is able to compensate for his defect so that it is not apparent to his associates. From childhood he has become familiar with color names as applied to common objects and uses these correctly. In other words, although he sees but a limited number of colors, he has adopted the nomenclature of the normal. He soon learns that other people use a color classification that is unnecessarily complex and full of hair-splitting distinctions and that his own ideas of color are apt to excite amused comment. Color to him is not a conspicuous quality of objects and he is not interested in it. He avoids using color names for unfamiliar objects until he has first heard them named by others and then employs them as a matter of memory. His memory for color itself is very poor. He looks at a red brick house surrounded by a green lawn adorned with red and yellow flowers. He sees all of these as varying shades of yellow but names the color of each correctly because he has learned by experience that bricks are called red and grass is called green and that this particular shade of yellow is usually called red and that one green. He will avoid referring to the color of the scarlet sweater lying on the lawn, however, because of uncertainty as to whether that shade of dark yellow should be called red, or brown, or green. He easily distinguishes traffic lights by a similar difference in shade because traffic lights are standard in color and intensity. If the intensity of the light were varied, he would be forced to rely on the relative positions of the red and green or to govern his own movements by those of the traffic.

Color to the normal-sighted is a conspicuous quality of objects; to the color-blind it is much less so. To the normal, colors differ from one another as to hue, luminosity, and saturation, that is, degree of admixture with white. Color differences are heightened by contrast. If a red is compared with a blue-green, the red becomes brighter and the blue-green becomes more blue. In the dichromat true perception is reduced from six units to two, but the contrast effect seems to be heightened and colors other than the two visible primaries are judged almost entirely by shade. Finally, the rays from the shortened end of the spectrum or the neutral band of the color-blind are not perceived at all; for him they are practically nonexistent. He can form no opinion in regard to their qualities, and in any mixture in which these physical units form a part of the exciting stimuli they will have to be subtracted before the result can be obtained. For this deficiency he is unable to compensate.

141. Trichromic color perception.—The spectrum consists of three colors: red, green, and violet (the latter often called blue). There may or may not be shortening at either or at both ends. The three primaries are distinct colors and are never mistaken for each other. They are in strong contrast as between their central points. The region of transition from one unit to the adjoining unit, however, partakes of the qualities of both and becomes a modified unit. The red-green junction appears as a mixture of red and green just as the yellow-green junction appears as a modified yellow-green unit in the normal spectrum. Trichromics frequently employ the term "reddish-green" or "greenish-red" in referring to this area. Such terms can have no meaning for the normal. Since the red-green junction of the trichromic lies in the yellow of the normal, he confuses shades of yellow with green and with red. Orange, yellow, and red-brown are put with red. Some yellow-browns are matched with red, others with green. Blue will be matched with violet or green. Red-violet causes much confusion; it is matched with red if the red element predominates in the mixture, with violet if either violet or blue is in excess, and with green when the red and the violet elements are approximately equal, that is, a mixture of the two end units of the three unit spectrum gives the middle unit.

Certain grays may be confused with green, but green is never called gray. The latter fact eliminates the possibility of a neutral band in the green. If red and blue are combined to form rose and the rose is then mixed with green, neutralization results and gray is produced for the normal. To the trichromic, however, blue lies in the violet and a mixture of red and blue is equivalent to mixing the two ends of the spectrum and, according to the laws of color, pro-

duces the intermediate unit—green. If now green be added the result is not gray as in the normal but merely more green.

Normal: Red plus blue=rose. Rose plus green=gray.
Trichromic: Red plus blue=green. Green plus green=green.

In figure 29 the spectrum in an actual case of trichromatism reported by Edridge Green is compared with the normal.

The yellow and orange region was not a distinct color to him but a transition from red to green which he thought should be called "reddish-green." The color was exactly the same to him as that of a field of red clover in full bloom. His matches were as follows:

Yellow.—All light colors. Red, orange, greenish-yellow, and brown.

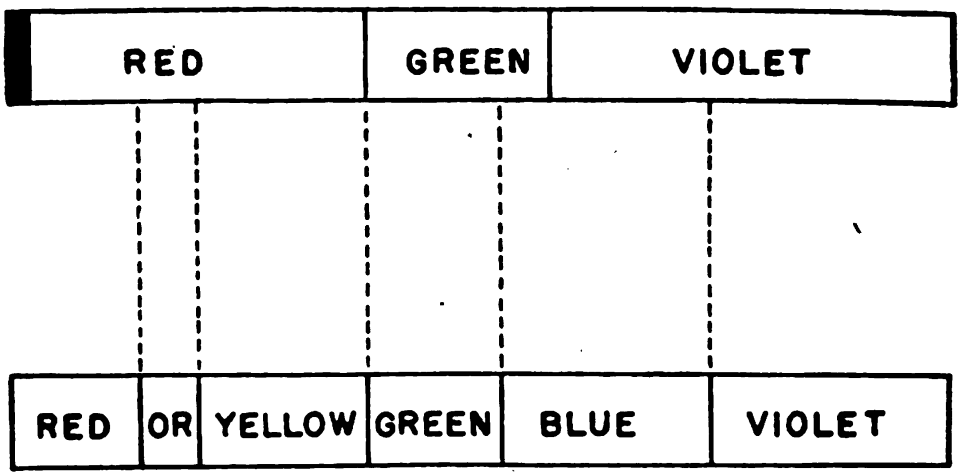


FIGURE 29.—Trichromic spectrum compared with normal.

Lavender.—Violet, purple, and gray.
Red.—Red, crimson, and orange.
Green.—Green and blue.

When told he had matched a gray with a lavender he showed the heightened simultaneous contrast phenomenon as follows: He compared the gray directly with the lavender and found that the gray now looked green. He then compared it with an olive-green and said that it now appeared purple. The lavender and the purple were placed side by side a few inches apart and the gray laid across them. The end resting on the lavender was green, the end resting on the green was purple, and the middle portion neutral in shade.

When tested with lanterns, red and green were named correctly under all circumstances, but yellow lights were confused with both red and green.

142. Dichromic color vision.—The various types of this, the most dangerous and the most common form of color-blindness, will now be considered; first, one of its rarer forms—simple dichromatism. Edridge Green states that he had examined 101 cases of color-blindness before he found an example of simple dichromatism (see fig. 27). The spectrum was of normal length; there was no neutral band. Only two colors were seen, yellow and blue, fading into one another; the neutral point was at the blue-green junction of the hexachromic; the center of the yellow, its most characteristic point and the most luminous point of the spectrum at the orange-yellow junction; most typical blue in the violet, just beyond the blue. He did not know that he was color-blind but said that he was not interested in color and knew little of it. Questioned as to the color of well-known objects, he answered correctly almost invariably, but called yellow bricks red; the orange glow of a coal fire, yellow in its brightest, and red in its darker part, and green where the coals were obscured by white ash; a man's complexion was white shaded with blue or purple, etc. Some of his matches were as follows:

Yellow, yellow-green, and orange.
Blue-green, gray, and crimson.
Red, orange, and yellow-brown.
Rose red, crimson, and purple.
Deep red, green, and brown.
Olive green, pure green, brown, and gray.
Blue-green, blue, purple, pink, and gray.
Blue, violet, and purple.
White, with very light shades of pink, green, brown and gray.

Tested with lights he called a yellow light, red; green obscured by a ground glass, yellow; a plain ground glass bulb was white over the filament and red elsewhere; on another occasion the same bulb was white and green; red obscured by a ground glass was green, etc.

It is scarcely necessary to state that this individual would be seriously handicapped in any occupation that required recognition of color or that his judgments based on color discrimination would be utterly unreliable. In fact, at first glance, it seems that there is no order or system in these diverse errors and we would be apt to assume that he is totally color-blind and that his matches are mere guesses. Such is not the case, however, and we will attempt to show by figure 30 that he has a color system of his own and to discover its rationale. In this connection two facts should be borne in mind. First, since there are only two colors in this spectrum, a mixture made up of color from one of its ends with the proper shade from the other end

will give white or a gray; that is, the two colors are complementary. Second, mixtures of spectral colors and mixtures of pigment colors are not exactly comparable. Spectral colors are pure colors. A quantity of spectral yellow can be represented by the formula $3Y^2$; the same quantity of a spectral blue by $3B^2$. On mixing these light rays, $3Y^2+3B^2$, the result is neutralization of both colors, white or gray. Pigment colors are not pure, but reflect waves of different lengths. The pigment owes its color to the fact that most of the rays of the other colors are absorbed whilst most of the rays of the typical color are reflected. A common pigment yellow then would have the formula $3Y^2+1G^2+1G^3$ and a pigment blue the formula $3B^2+2G^3+1V^1$. Now if these two are mixed the yellow absorbs the blue rays and the blue absorbs the yellow rays and only the green rays are reflected. $(3Y^2+1G^2+1G^3)+(3B^2+2G^3+1V^1)=1G^2+3G^3+1V^1$. In other words, when the spectral colors are mixed the result is obtained by addition; when pigment colors are mixed the result is obtained by subtraction.

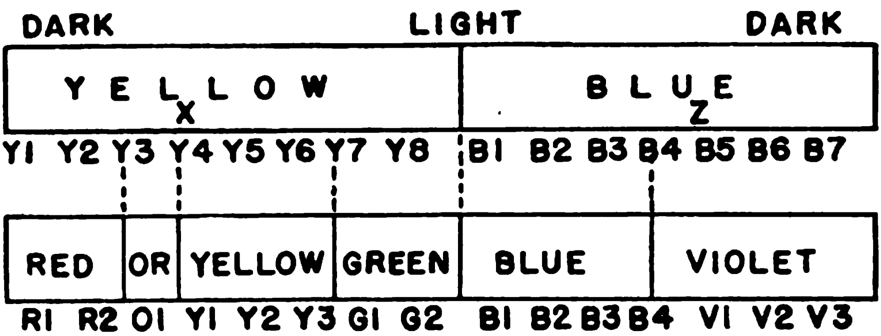


FIGURE 30.—Simple dichromatic spectrum.

The point of maximum luminosity of the spectrum and the most typical yellow are represented by X; the most characteristic blue by Z; the shades of the several colors by the appropriate initial followed by a numeral. The dichromic equivalent of any color in the normal spectrum can be approximated by direct comparison of the two spectra. Likewise, if the exact composition of a mixed color is known the dichromic equivalents can be substituted in the formula and the dichromic result can be calculated, for example, R^2+B^2=rose. Dichromic equivalent: Y^2+B^2=gray, or more commonly (due to the fact that the blue is less luminous than the red) a shade of blue or bluish gray.

Consider the match, blue-green, gray, and crimson, made by this examinee:

Hexachromic perception	Dichromic equivalent
Blue-green $= B^2 + G^3$	$B^3 + Y^3 =$ a shade of gray.
Gray	Gray.
Crimson $= 3R^1 + V^3$	$3Y^1 + B^6 =$ dark brownish gray.

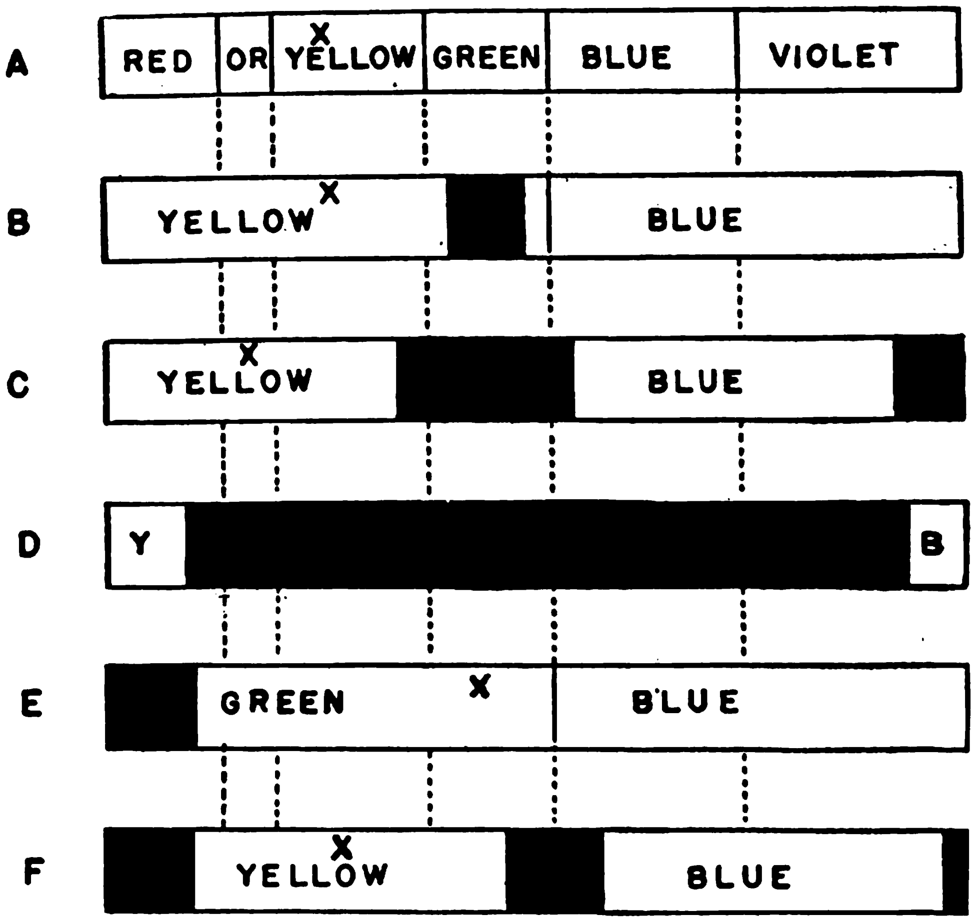
Brown is a shade of dark yellow or orange. In this case a part of the yellow is neutralized by the blue and makes gray, so the end result is a blend of gray and brown with the brown predominating. If the proportions of red and violet in the crimson be varied the result for the dichromat may be dark bluish gray or a blue. In the match yellow, yellow-green, and orange, the three shades are on the same side of the spectrum and would be perceived as three values of yellow, Y^5, Y^7, and Y^8.

This case of simple dichromatism is not an extreme example of color-blindness; on the contrary, his color perception is much better than that of any of the common types of dichromatism. These types arise when the dichromic spectrum is still further impaired by the presence of a neutral zone in which no color is perceived. The neutral area may occur as a shortening at the red end, as a shortening at the violet end, as a band of variable width centering in the green, or as combinations of these three.

In figure 31 types *B* and *C* are ordinarily referred to as deuteranopes or green blind, the most common form of dichromatism. Types *E* and *F* are called protanopes or red blind. This classification is based on the location of the neutral band. It is apparent that if the neutral band is located in the green, the defect in perception of green will be more obvious than the defect in red perception, since there is no sensory basis for a judgment respecting green, whereas an opinion as to red can be reached on the basis of the shades of yellow that are perceived in the red area. In this classification a spectrum shortened at the violet end would be called violet blind, but since inability to distinguish between dark violet and black is of little practical importance, there are relatively few references to this type. This nomenclature, therefore, is based on the location of the neutral band and takes no account of the reduction in the number of psychophysical units.

All types of dichromatism will make mistakes similar to those made by the simple dichromic case that we have considered. In addition to these the dichromat with a shortened spectrum or a neutral band will match colors corresponding to the neutral area

with black if the color be dark, with gray if it be more luminous. In mixed colors the color from the neutral area does not enter into the mixture except as a black or gray. The only effect of its presence, therefore, is to produce a darkening of the mixture. Since the green is a very luminous area of the spectrum, the neutral band in the green appears gray, and these individuals frequently match



A Normal hexachromic spectrum.
B Spectrum of normal length. Neutral band in green.
C Spectrum shortened at violet end. Neutral band in green.
D Very wide neutral band. Practically totally color-blind.
E Spectrum shortened at red end.
F Spectrum shortened at both ends. Neutral band in green.
X Indicates point of maximum luminosity.

FIGURE 31.—Various types of dichromatic spectra.

dirty white or white shaded with some color with the green. The ends of the spectrum being darker appear black if there is a terminal shortening; hence deep, pure reds or violets are matched with black; pale shades of pink (red and white) may be put with light grays, etc.

143. Effect of a shortened red.—A shortening of the red end of the spectrum produces defects that are of considerable practical importance. The red rays from the extreme left of the spectrum are the most penetrating and visible under conditions of obscurity. This explains the red appearance of the sun through a smoked glass. The other rays are cut off, but the extreme red penetrates the smoked glass. We have seen that signal lights, rockets, flares, etc., are composed of a mixture of rays; hence, if the observer is unable to perceive the red rays because of a shortened spectrum, the red signal light will be invisible at a distance or under conditions of obscurity; on approaching closer to the light the perception of green and blue rays will cause the light to appear green.

All colors reflecting rays from the shortened portion appear darker than they do to the normal-sighted and are matched with darker colors that reflect rays from a point more internal. Hence a dichromat with a shortened red will match a red with a darker green. Another common mistake is the confusion of pink and blue. If the pink is composed of red and violet and the red rays come from the shortened portion of the spectrum, only the violet is perceived and it is seen as a blue. The effect, then, is blue mixed with black; that is, a dark blue. Hence the common confusion of pink with a darker blue or violet.

For convenience in reference two tables are now given. The first shows the common color confusions of the color blind and indicates the diagnostic significance of each. In the second table the result of a mixture of spectral colors is found at the intersection of the horizontal and vertical columns. It should be remembered that these results do not apply in mixtures of pigment colors, since these are compound colors and the result is obtained by subtraction.

TABLE I.—*Diagnostic import of common color confusions*

Confusion of	Significance
Red and black	Shortening of red end of spectrum.
Violet and black	Shortening of violet end of spectrum.
Blue and black	Neutral band extending into violet.
Green and black	A dichromat with neutral band in blue-green.
Any mixed color with black or gray.	A dichromat for whom two colors are complementary; that is, when mixed, they form gray.
Red and green	Practically diagnostic of dichromatism (2 unit).
Green and brown	Practically diagnostic of trichromatism (3 unit).
Blue and green	Practically diagnostic of tetrachromatism (4 unit).

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TABLE II.—*Results of mixture of primary (spectral) colors*

	Violet	Blue	Green	Yellow	Red
Red	Purple	Rose	Dull yellow	Orange	Red.
Yellow	Rose	White	Yellow-green	Yellow.	
Green	Pale blue	Blue-green	Green.		
Blue	Indigo	Blue.			
Violet	Violet.				

144. Military significance of color-blindness.—*a. General.*—The various types and degrees of defective color perception give rise to a great diversity of color confusion, many of which are of a bizarre nature and are apparently inexplicable on superficial examination. The color-blind learn to adjust to the defective color perception and some cases compensate so well that the defect is not only not apparent to their associates but may not even be known to themselves. The dark yellow, the bright yellow, and the pale yellow traffic lights of the dichromat are, for all practical purposes, as effective as the red, orange, and green lights of the normal-sighted. In fact, it seems probable that a totally color-blind individual would be able to distinguish the traffic lights by the difference in luminosity; if not, a satisfactory adjustment could easily be made on the basis of the relative position of the lights; as a last resort he could always follow the traffic. The military significance of color-blindness is discussed below. First it is considered in relation to the arm that has a very high standard, the Air Corps.

b. Air Corps.—In the physical examination of applicants for flying training considerable importance is attached to the detection of color-blindness. The reason for the stress placed on the detection of this condition in prospective military aviators may be briefly outlined as follows:

(1) *Requirements.*—(*a*) Recognition of various luminous signals such as field boundary lights, obstruction lights, navigating lights, and rocket signals. Distinctive colors are employed to signify various vital conditions and prompt comprehension of their portent is essential for efficient military flying.

(*b*) Recognition of colored flags and other daytime signaling devices.

(*c*) Ability to discriminate between varying conditions of terrain by the colors thereof. For example, a field of a certain shade of green may indicate a pasture or similar area or short grass whereon a safe landing can probably be made. An adjacent flat area of different shde of green may indicate a soft boggy marsh where a dangerous nose-over or even a bad crash may be anticipated. Again, a brown area indicates a plowed field with soft and dangerous surface, and in some cases its condition as to saturation with water may even be detected by variations in shade. Nearby may be an area of yellowish-brown differing very little from the plowed field in color, but with sufficient difference to indicate that this is a field of dried grass or short dry weeds, which may prove a safe place to put the wheels down. In a forced landing on difficult or dangerous terrain, when the pilot has but a few seconds to locate the most desirable spot to effect a landing, the accuracy of color discrimination is of vital importance, because once he has chosen a field and has lost altitude in reaching it, there is no opportunity to make a second choice. Rain, light fog, and cloudy conditions, especially in the early morning or toward evening, render color discrimination from an altitude very difficult, even for the normal eye; for the individual with inadequate color discrimination, such conditions will prove supremely hazardous and may easily end in disaster.

(2) *Elimination*.—It is believed that the elimination from flying training of individuals with moderate degrees of color-blindness should be accomplished. The following classes, therefore, should be excluded:

(*a*) Those who see three or less colors in the spectrum.

(*b*) Those who, while being able to perceive four or five colors, have the red end of the spectrum shortened to a degree incompatible with their recognition of a red light at a distance of 2 miles.

(*c*) Those who are unable to distinguish between red, green, and white lights at the normal distance, through insensitiveness or defect of the cerebral retinal apparatus, when the image on the retina is diminished in size.

(*d*) Those who have difficulty in distinguishing varying shades of yellow, orange, and brown. This would include the four-color individuals, tetrachromics, and the five-color individuals, the pentrachromics.

(3) *Acceptance*.—This leaves only the six-color or hexachromic individuals, the so-called normal, who should be accepted for training in military aviation.

(4) *Effect of excitement*.—It has been found that individuals with defective color vision, even almost approaching the normal, when

subjected to excitement or nervousness, frequently suffer a reduction in their color discrimination, reducing them to a lower grade. Thus, while the trichromics do not mistake red for green ordinarily, but confuse yellow with red and green, they may, when subjected to excitement, find their color discrimination reduced to the dichromic state and are apt to mistake a red light for a green one or vice versa. Persons eliminated in the second class, namely, those with shortening of the red end of the spectrum, should be excluded because, while they may be able to distinguish red lights of certain shades and of sufficient intensity, which they are very close to, may fail to distinguish them at a distance or when dim, or if that particular shade of red is outside their range. Unfortunately, many signal lights are of a shade of red near the end of the spectrum.

c. Arms.—For the majority of line officers, color-blindness probably interferes chiefly in the ability to recognize signal lights, especially at a distance or through fog or smoke. The use of maps printed in several colors would be difficult until the defective color perception could be compensated for by practice. In various kinds of observation work, inability to distinguish tints and shades in the landscape would be a serious drawback. Satisfactory artillery observation would probably be impossible. The colored markings of the various types of shell, grenades, gas shell, etc., would present great difficulties. The officer of the Signal Corps would have great difficulty with the colored stripes woven into the insulation of wires and cables.

d. Veterinary Corps.—In order to grade hay, the officer of the Veterinary Corps must have hexachromic color perception, with good shade discrimination. The color shades of hay are just the shades that a color-blind individual has trouble with and he would be unable to compensate for the defect. His ability to inspect meat would be impaired to some extent, but the possibility of compensatory adjustment would be greater.

e. Medical Corps.—Perhaps the most obvious handicap is in the chemical laboratory; so many tests depend on color reactions. It would be difficult to imagine an individual more seriously handicapped for colorimetric work than a dichromat with extensive neutral areas in the spectrum. In microscopy, also, with its dependence on differential staining, the color-blind find it extremely difficult or impossible to compensate for the defect. Take the case of a dichromat who describes a man's complexion as "white shaded with purple or blue," and a child's red lips as a "sort of blue." One can only speculate on his sensations when viewing the rash of scarlatina or measles, the retina through the ophthalmoscope, icteric skin, and sclerae. What would he make of Koplick's spots, of a strangulated loop of gut, of the streptococcus

throat, of the cyanosis of decompensated heart disease, of a furuncle, of lupus erythematosus? How accurate would he be in Fehling's or Benedict's test; in testing for occult blood, for biliuria; in hemoglobin estimation; in differential blood counts, or in examining stained slides for malarial parasites or Gram negative organisms? It is undeniable that the color-blind compensate surprisingly well in many such situations; nevertheless, they are at a distinct disadvantage as compared to individuals with normal color perception. The color-blind medical officer can conduct the examination for color-blindness in a mechanical way and if he knows the exact nature of his own defect may be able to use the wools satisfactorily. The handicap is obvious, however.

145. Tests of color vision.—*a. General.*—Of the great number of tests that have been devised for the detection of defective color perception, only three types will be mentioned. Representatives of these three types are in common use and it is on these that we rely in our examinations. The advantages and limitations of each and the relative value of the three are of practical importance. These tests are:

(1) Self-recording type—exemplified by the Jennings.

(2) Pseudo-isochromatic plates—exemplified by the Stillings and the Ishihara.

(3) The wool yarn tests—usually the Holmgren or one of its numerous variants.

b. Jennings self-recording test.—The advantages of this test as usually recited are: it is compact; the skeins are not exposed to fading or soiling; the examinee makes a permanent record of his own color perception; it can be given rapidly and is well adapted for the processing of large numbers of examinees. The objections are that the results are not uniform; the examiner is often in doubt as to whether the candidate should be accepted or rejected; normals not infrequently make mistakes with the test and many of the color-blind pass it without difficulty. As a result of this, some examiners adopt a working rule to accept the candidates who do not make more than a given number of errors and reject those who do. Such practice merely multiplies the imperfections of the test, and if the number of allowed errors is considerable, render it practically valueless, for it is the kind of mistake and not the number of mistakes that is significant. It is obvious that to punch a lavender as a shade of the rose test skein might have no significance, whereas if blue is punched in rose test or red in the green test we would be correct in concluding that the individual is markedly color-blind. To consider a lavender a pale shade of rose is a mistake that is made by normal hexachromics. To match a pure blue with rose or red

with green is comparable to mistaking a 5-ton truck for a baby's perambulator, and is conclusive evidence that the individual is color-blind.

The Jennings test, like the Holmgren, uses the shade of green that corresponds to the usual location of the neutral band in dichromatism. The punching of grays, therefore, or the omission of some of the greens is highly significant. The rose skein is composed of equal values of red and blue. A match with a darker blue would indicate a shortened red, etc.

In the opinion of the writer this test is of limited value. It is not so flexible as the Holmgren test and the suitability of some of the yarns seems open to question. Some dichromats pass the test even under the best conditions. If the test is not carefully given and interpreted a considerable proportion will pass it. The test is of value when a large number of candidates are to be examined in a limited time. The entire group can take the Jennings test in a short time, those making a perfect score can be passed without more ado, and all of those who make any mistakes can be reexamined by more accurate methods.

c. Pseudo-isochromatic plate tests.—These tests, familiar as the Ishihara and the Stillings, are by all odds the best tests to use in routine examinations. The test can be given quite rapidly and a permanent record of the result can easily be made on a typed or mimeographed sheet by filling in the numbers as called by the examinee, opposite the proper plate designation. The plates should be exhibited in irregular order and the plate designation should always be concealed from the examinee. These tests are now quite well known and the possibility that a poor color sense may be fortified by an excellent memory should be kept in mind. This is especially true in the Ishihara test with its less numerous plates. The Stillings test is facilitated if one of the obvious plates (XIII 1 or XIII 2) is shown first. Much time is often saved if the examinee is told at the beginning of the test that he will be shown a series of colored plates, some of which bear numerals, others do not, and that he is not to waste time in looking for numerals that he does not see. Plates XIII 1, XII, and XIII 2 are then exhibited in the order named, the responses are recorded, and the remaining plates are shown in irregular order.

d. Wool yarn test.—This familiar test employs the green and the rose test yarns as does the Jennings test. In fact the Jennings is but a modification of the Holmgren. In addition a bright red skein is used. This gives but little additional information as a rule, unless there is considerable shortening of the red. If the wools are used carefully

according to directions, most of the dichromats and some of the shortened red cases will be detected. If the examiner is content when the examinee puts up one or two skeins for each of the test skeins, the test may be almost valueless. Hesitancy, selecting a skein as a match and then withdrawing it after direct comparison with the test skein, and failure to put up all skeins are all as significant as actual errors in matching. An individual with normal color perception does not examine a skein of a color different from the test skein carefully and critically, turning it over in his hands the while; nor is it necessary for him to make a direct comparison to determine that a gray skein is not green or that a blue skein is not pink. In such cases the existence of defect in color perception is evident; it is only necessary to continue the test in order to determine its type and degree. When skeins that are of the proper color are not put up with the test skein the examiner should at once ask himself why these skeins were omitted. The omitted skeins should be noted, all skeins should be mixed together, and then one or more of the omitted skeins should be used as test skeins.

The wool test should be regarded not as a set test to be carried out according to certain printed instructions but should be considered rather as a convenient source of colored materials for the detailed investigation of the color perception. If the set contains a large number of skeins, a rough though adequate representation of the hexachromic spectrum can be outlined and the examinee can be asked to make matches from one end to the other; or he can be tested for shortened red by laying out a red series for matching, likewise for the violet and the green. The problem can then be approached by laying out several series of confusion colors for matching, black to gray, brown to tan, purples, olive greens, etc. The examinee should always be afforded opportunity to make the characteristic confusions. Used in this way the wool skeins are of great value and given a fairly accurate picture of the state of the color perception.

e. Conclusion.—It is believed that the Jennings test should be reserved for the preliminary survey of large groups; that the pseudo-isochromatic plates should be used whenever it is practicable to do so; that final decision in doubtful cases or in cases in which there is some indication of abnormality should be made on the result obtained with the plates; and finally that a set containing a large number of wool skeins should be available for the further investigation of some special defect or to confirm the results obtained with the plates. With this procedure very few cases of defective color perception will escape detection.

146. Examination of color perception.—In an article in Army Medical Bulletin No. 34 (January 1936) attention was called to the unsatisfactory results that were being obtained in the examination of the color perception of candidates for West Point, candidates for commission, and applicants for appointment as flying cadets. Since that time progress has been made in the detection of this defect and a study of this subject has been carried out. An effort has been made to determine the relative value of the various tests that are in common use and it is believed that a method of examination can now be outlined that will meet the requirements of the Medical Department as to simplicity, speed of examination, and a reasonable degree of reliability.

During the years 1934 and 1935, 2,355 candidates were examined for admission to West Point. Of this number 20 or 0.84 percent were found to be defective in color perception. During the year 1936, 1,751 candidates were examined; of this number 47 or 2.68 percent were disqualified because of this defect. This indicates that there has been considerable improvement in the conduct of this examination and that we now accept fewer candidates than formerly who are actually disqualified because of defective color perception. It is noted, however, that this improvement was by no means universal and that there was great discrepancy in the findings of the various examining boards and that some of these boards still fail to detect this very common and obvious defect. This is best illustrated by comparing the findings of some of the boards that conducted the examination in March 1936.

Board number	Total examinees	Cases of defective color perception	Percentage
1	7	2	28.56
2	16	0	
3	22	0	
4	23	2	8.19
5	25	0	
6	26	3	11.43
7	28	2	7.14
8	32	0	
9	51	3	5.88
10	98	7	7.14
11	102	4	3.92
12	154	10	6.49
13	100+	0	

Where small numbers are involved, discrepancies are naturally to be expected. It may be said that Boards 1, 4, 6, 7, 9, 10, 11, and 12 probably detected every case of significant impairment of the color perception among the candidates examined. It is quite likely, but by no means certain, that Boards 2, 3, 5, and 8 did also. As for Board 13, which examined more than 100 candidates and found them all normal as to color perception, the chances are somewhat more than 200 to 1 that a group of this size selected at random would contain at least one individual with defective color perception. Results of this kind are usually obtained when the examination of the color perception consists of a perfunctory test with the yarns.

One board that examined a large number of candidates found the normal number of cases of color-blindness by use of the pseudo-isochromatic plates. These candidates were then put through the yarn test and all of them were reported as normal to the yarn test. Such results are reminiscent of certain recent nation-wide polls and like them justify the assertion that "somebody was wrong." If a candidate reads plate 3 of the Ishihara test as "5" or is unable to read the numbers of plate I 2 of the Stillings (17th edition), it can mean only one thing; namely, that the shades of red and green in these plates are to him so nearly alike that the red numeral does not contrast with the green background sufficiently for him to see it. Likewise, obvious difficulty in reading these plates—tracing out the numeral with the finger, changing the angle of illumination, etc.—are certain indications that although the two colors (red and green) are not quite the same the contrast between them is much less than to the individual with normal color perception.

Now, if the examinee is unable to distinguish between the shades of red and green in these plates he will have the same difficulty in differentiating the same shades of red and green yarns. The woolen skeins possess no superior chromatic quality; there is no magic that will enable him to distinguish between these shades in the one situation when he is unable to do so in the other. In using the yarn test, two things are necessary: first, the set must contain a sufficient number of skeins of unsaturated reds and greens, the same, or similar shades, as those used in the plates, and a large number of confusion skeins; second, the examinee must be required to distinguish between them. If the test is conducted so as to give him an opportunity to make the characteristic mistakes, he will make them.

Such discrepancy in the results of the examination with the plates and with the yarns is apparently due to two causes: first, improper conduct of the examination; second, a set of yarns that is inadequate for the purpose. Some sets of yarns are so abbreviated that only the

well marked cases of dichromatism can be demonstrated with them. This phase of the problem will be discussed in more detail when we consider the tests themselves.

The Surgeon General's Office frequently receives reports of physical examination in which it is set forth that the examinee fails to pass the Stillings or the Ishihara test, but makes no errors when tested with the Holmgren (yarn) test. Often this supposed ability to pass the yarn test is made the basis for a recommendation for waiver. Inquiries have been received as to the "official test" of the color perception and whether an examinee can be considered normal when he passes the yarn test but fails to read the plates correctly.

When this proposition is stated in clear terms the answer is at once evident. The question of color-blindness, like other disqualifying defects, is a question of fact and not a matter of being able, under certain abnormal conditions, to get through a particular test. Any material impairment of the ability to perceive red or green or violet disqualifies under the regulations. The particular method employed for the detection of the defect is of no special importance. It is important that the defect be detected. In the examination of the color perception, as in all other examinations, the method of choice is the one that gives the most accurate results—that reveals the defect in the greatest number of cases and fails to reveal it in the smallest number of cases.

Consider the case of the examinee who fails when examined by the Ishihara test, but is said to make no errors with the yarns. This anomalous finding, as well as some of the other problems that arise in the examination of the color perception, is best illustrated by reporting an actual case in which the Holmgren yarn test was first used incorrectly, with the usual result that the chromatic defect was not demonstrated. On reexamination some weeks later with the Holmgren test, employing the proper technique, the impairment of the color perception was at once evident. In the period intervening between the two examinations, however, the examinee had familiarized himself with the Ishihara and the Stillings plates, with results which he considered highly satisfactory, but which to the experienced examiner merely served to confirm the known fact that there was a red-green deficiency and revealed the lengths to which the candidate would go in order to conceal it.

147. First examinnation.—*a. Ishihara plates.*

Plate number	Reading
1	12.
2	3.
3	5.
4	2.
5	21.
6	No numeral.
7	No numeral.
8	No numeral.
9	No numeral.
10	5.
11	2.
12	26 (hesitant on the 6).
13	42 (hesitant on the 2).
14	Traces blue lines—hesitant.
15	Cannot trace.
16	Traces blue line easily.

b. Holmgren test (improperly given).

Examiner: [*Spreads yarn on table; holds up green test skein.*] What color is that?

Candidate: Green.

Examiner: All right, pick out some greens.

[*Candidate rapidly selects six well-saturated green skeins and puts them with test skein.*]

Examiner: [*Picks up red test skein.*] What color is that?

Candidate: Red.

Examiner: All right, pick out some reds.

[*Candidate rapidly selects four typical reds.*]

Examiner: [*Exhibiting rose skein.*] What color is that?

Candidate: [*Handling skein.*] I don't know much about the names of colors. It is a reddish purple or lavender. It has blue in it and some pink. I guess I am color ignorant, but I am not color-blind. I can see them all right, even if I don't know all of the names.

Examiner: All right, pick out some skeins that are the same color.

[*Candidate somewhat hesitatingly selects one dark red and two rose skeins.*]

Examiner: [*Exhibits several blues and yellows, which are correctly named.*] Have you ever had any trouble in distinguishing colors?

Candidate: No, never. I don't know the names of a lot of different shades, but I can see them all right. I drive a car and I never have any trouble with the traffic lights.

The examiner reports as follows: "Fails to read the Ishihara plates correctly, but is normal to the yarn test. Not a case of true color-blindness, but is color ignorant. No clinical significance." "Does he meet physical requirements?" "Yes."

Note.—The set of yarns used was an adequate one and would have revealed the defects under proper conditions.

When a candidate is examined in this manner, it is to be expected that he will select those skeins that seem to him to have a definite color and that he will avoid all doubtful skeins. There are very few dichromats who cannot identify some reds and greens. They perceive both red and green as shades of yellow, but have little difficulty in distinguishing well-saturated reds and greens by the difference in brightness. As a matter of fact, such methods of examination have resulted in the detection of only about one-sixth of the candidates who have significant abnormality of color perception.

148. Second examination (three weeks later).—*a. Ishihara plates.*—(1) *Test.*—Plates 1, 2, 3, 4, and 5 were read correctly, with slight hesitation in the case of plate 5. Plates 6, 7, 8, and 9 were shown in irregular order. All were read correctly, but with obvious difficulty; the book was held at varying distances from the eyes and the angle at which it was held was changed. It was plain that the numerals on these plates afforded no effective contrast with the background. With plates 10 and 11 there was a rather elaborate show of close scrutiny, but after an interval the candidate stated that he could see nothing in the plates. Inability to read these plates is not compatible with difficulty in reading plates 6, 7, 8, and 9. In addition, it was known that when first examined the candidate had read plates 10 and 11 without difficulty. Plates 12 and 13 were read correctly without hesitation. He was then asked which of the two numerals in each of these plates stood out more clearly. This was apparently a difficult question, for he had difficulty in understanding it. He then made a show of scrutinizing the plates while he thought the matter over. He finally stated that the first digit (2) in plate 12 and the second digit (also a 2) in plate 13 were more distinct than the others. Plates 14 and 15 could not be traced satisfactorily, though by close application he was able to follow the line slowly for short distances. In plate 15 he tended to jump across the intervening spaces where the loops came close together. In plate 16 he made a show of attempting to follow the irregular reddish lines.

(He had traced the pale blue line with ease and confidence at the first examination.)

(2) *Comment.*—Reading of the first five plates correctly seems to indicate normal color perception, but the difficulty in reading plates 6, 7, 8, and 9 shows that the ability to distinguish between red and green is much impaired. This is confirmed by the inability to trace the line in plates 14 and 15 easily and rapidly. The alleged inability to read plates 10 and 11 and to trace plate 16 is incompatible with the difficulty manifested in reading plates 6, 7, 8, and 9 and in tracing plates 14 and 15. Finally, there is the discrepancy in his statement about the relative distinctness of the digits in plates 12 and 13.

If the candidate reads plates 12 and 13 correctly he should always be questioned as to the relative distinctness of the two numerals on each of these plates. Often the manner of reading will give a clue. The protanope sees the first digit as a shade of black; that is, gray. It may match the background so perfectly that it is invisible; there may be enough difference so that he can make it out. He sees the second digit as a darker blue or purple, but it affords an effective contrast; hence is read without difficulty. The deuteranope sees the first digit as a shade of yellowish brown, a fairly strong contrast to the background. The second digit is made up of equal values of red and blue, rose to the normal. These shades come from opposite sides of the dichromic spectrum, they are to him complementary colors and when combined produce not rose but neutrality or gray. Hence there is little or no contrast to the background; hence the deuteranope sees the second digit with difficulty, if at all.

(3) *Conclusion.*—Candidate is an individual with defective color perception who has studied the plates and who, in attempting to conceal his defect, does not hesitate to make untruthful statements about what he actually sees.

b. Stillings plates.—(1) *Test.*—Most of the plates were read correctly, though there were errors as between 3 and 8, 3 and 5, 7 and 9, etc. A few major errors were made, and two and one-half plates could not be made out at all. All of the plates were read with great difficulty after the manner of one who is trying to solve a difficult puzzle. No plate involving a discrimination between red and green was read with ease and certainty. In some of these the reading was made only after the numerals had been laboriously traced out with the finger. The plates that require a discrimination between blue and green were read with greater facility than the red-green, the red-brown, and the green-brown ones. The ability to read these blue-green plates seems to equal that of many normals.

(2) *Comment.*—It is evident that the shades of red and of green used in these plates are so nearly alike to the examinee that there is no effective contrast and that he probably could not read these plates at all if he had not previously studied them. It is as though a normal individual attempted to visualize a numeral delineated in light gray against a gray background that is only slightly darker.

c. Holmgren yarn test (properly conducted).—(1) *Test.*—The yarns are spread on a table that is covered with a sheet. The examinee is seated at the table. The yarns are illuminated by diffused daylight (not sunlight) that comes from the windows behind and to the left of the examinee. The yarn box is placed at the right and the top of the box at the left of the yarns. The red test skein is placed against a piece of cardboard at the other side of the table, directly opposite the examinee. The distance from the examinee is 3½ feet. The test skein is so placed that both it and the small skeins are not in the examinee's visual field at the same time. He must raise his head slightly to see the test skein and must look down to see the heap of small skeins. To bring them both into his visual field he must take up a small skein and extend his arm slightly. Only by doing this can he make matches by direct comparison, and it is important for the examiner to know if it is necessary for him to resort to direct comparison in order to make a decision. The normal individual does not need to bring a gray skein or a brown skein into the same visual field with the test skein in order to decide that it is not red. The color-blind often find this necessary. If it is done it is positive evidence of defective color perception, whether the skein is properly classified in the end or not.

Examiner: [*Takes up a skein from the table.*] I want you to take up these skeins one by one and look at them. All skeins that are a shade of that color [*points to test skein*] put in this box on your right. All skeins that are not a shade of that color put in this box on your left.

Candidate: Do you want me to put everything that has red in it in this box? I am not sure that I know what you mean by shades of colors.

Examiner: Name some colors for me.

Candidate: Yellow, blue, red.

Examiner: Now, what do you mean by a shade or tint of yellow or blue? How do you refer to shades of a color? Do you refer to them as rough or smooth, as sweet or bitter, as large or small?

Candidate: Dark or light.

Examiner: Then you would refer to shades of blue as dark blue, medium blue, light blue, and so forth?

Candidate: Yes.
Examiner: But they are all blue?
Candidate: Yes.
Examiner: All right. Put in this box all shades of that color. Put all shades of all other colors in that box.
Candidate: But suppose that a skein has both blue and green in it, how will I know whether to call it blue or green?
Examiner: Look at it and make up your mind whether it should be called a blue or a green and place it accordingly. After all, fine distinctions of shade are matters of opinion and there is no reason to think that your opinion is not as good as anybody's. This test is not designed to trick you, but merely to find out whether you have the normal ability to perceive colors. We are not interested in your ability to name or to classify shades and tints, but in your ability to perceive colors. So, put all shades of that color (pointing to red test skein) in this box and all shades of all other colors in that box. Now, let's get started.

(2) *Comment.*—This rather tedious colloquy is fairly characteristic of the questions that some candidates ask. All of them do not ask so many, some ask more. Numerous questions and objections are raised by two classes of examinees. First, those who are defective in color perception. They ask questions in an attempt to establish some criterion other than their own sensations by which a decision can be made. Second, the overconscientious introvert type. Their sense of color may be above the average, but in this as in other matters they want specific directions, which they will then follow with exactitude down to the most minute detail. It is believed that the examiner's part in this discussion is of some importance. For example, if the examiner gives an affirmative answer to the question, "Do you want me to put everything that has red in it in this box?" the protanope will have an alibi when he selects dark purples as matches for the rose or the red test skein. Such instructions will sometimes lead the intellectual and overconscientious examinee into the same error, not because of defective color perception, but because of his judgment as to the composition of the color in question. The examiner should avoid, so far as possible, the mention of color names or reference to their composition, and should limit himself to directions to, "Put all shades of that color in this box and all shades of all other colors in that box." The meaning of the terms "shade" or "tint" should, of course, be made clear if they are not understood.

(3) The candidate proceeds with the sorting. Results as follows:
Red test skein:
Number of red skeins selected—21.
Number of red skeins omitted—none.
Number of other colors selected—1 bluish gray.
Manner of performance—confident and fairly rapid.
Matches by direct comparison—none.

(4) The examiner checks and records the results. He notes the gray skein selected as a red, but gives no indication of his opinion of any selection. The skeins are mixed and spread on the table; the examiner replaces the red test skein with the green test skein and says, "Put all shades of that color in this box and put all shades of all other colors in that box."

Green test skein:
Number of green skeins selected—26.
Number of green skeins omitted—none.
Number of other colors selected—1 light brown.
Manner of performance—confident and fairly rapid.
Matches by direct comparison—none.

(5) The examiner records the results, makes a mental note of the erroneously selected brown skein, but gives no indication of his impression. The skeins are again mixed and spread on the table, the green test skein is replaced with the rose and the directions are repeated. The candidate leans forward and looks at the test skein intently for a moment and then proceeds with the sorting. He works rapidly, but shows a tendency first to pick out yellows, well saturated greens, and bright blues and put them into the box on his left. He picks up a gray skein that has no vestige of color; he turns it in his hand; he raises the hand, extends the arm, and looks over the gray skein at the test skein. He decides that it is not rose and tosses it into the box on his left. He takes up a light gray and tosses this into the right hand box as a shade of rose without direct comparison. Final sorting as follows:

Number of rose skeins selected—24.
Number of rose skeins omitted—none.
Other skeins selected—4 (1 pale lavender, 1 light gray, 2 steel gray).
Manner of performance—fairly confident.
Matches by direct comparison—3 (2 gray, 1 lavender).

(6) The procedure is repeated, the light brown skein that was selected as a green is used as a test skein and the candidate is again instructed to sort the skeins.

Number of brown skeins selected—34.

Number of brown skeins omitted—3.
Number of other colors selected—none.
Manner of performance—confident.

This result was rather surprising, as it had been expected that he would select some pale greens as matches for the tan.

NOTE.—The more usual result is that obtained in the recent examination of a deuteranope who selected a gray skein as a match for the green test skein. This gray was noted and after the sorting had been completed and the skeins mixed this gray was put up as the test skein. The examinee studied it for a moment and then remarked, "Another green, eh!" He then proceeded to select most of the greens and all of the grays that were about the same shade. No more conclusive evidence of the defect in color perception could have been given.

(7) The skeins are mixed, one of the gray skeins that was selected as a rose is put up as a test skein, and the instructions are repeated.

Number of gray skeins selected—1.
Number of gray skeins omitted—4.
Other colors selected—4 (1 light blue, 1 bluish white, 1 light pink, 1 pale lavender).
Manner of performance—confident.
Selections by direct comparison—none.

Examiner: [*Spreads yarns on table.*] I want you to cast your eyes over these yarns and pick out for me the three skeins that are the most brightly colored. It makes no difference what the color is or whether they are all the same color or not. Just get the three that seem to stand out most distinctly.

Candidate: Selects (1) bright yellow; (2) bright orange; (3) dark red.

(8) *Comment.*—(1) and (2) can fairly be considered as among the brightest colored skeins on the table, but there are at least 12 skeins that are more conspicuous than (3), the well saturated red. It has been observed that in this simple test the color-blind tend to select yellows and blues rather than reds or greens, and that when reds or greens are selected they are the darker, well-saturated shades; for example, this candidate passed over four vivid reds that were conspicuously placed to select a dark, inconspicuous shade.

(9) *Impression.*—A very mild degree of deuteranopia or red-green color-blindness of the green type. This is based on the following consideration:

(*a*) Difficulty in reading and in tracing plates involving red-green discrimination shows that to him there is but little difference in the shades of red and green used in the plates. He probably sees them

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as two shades of brownish yellow. This is confirmed by the matching of a brown skein with the green.

(*b*) A mixture of red and blue that makes rose for the normal individual is gray to him or nearly so. In other words, red and blue are complementary colors for him. This is evidenced by the indistinctness of the rose-colored numerals against a gray background in Ishihara plates 12 and 13 and by matching gray skeins with rose in the Holmgren test.

(10) In view of the fact that color blindness disqualifies under the regulations and the disqualification includes the mild as well as the pronounced cases, the examiner properly reported that he did not meet the prescribed standards. It was thought, however, that the defect in this candidate was of such mild degree that it was devoid of any practical significance and could not possibly interfere with the performance of any military duty. It became necessary to revise this appraisal after further investigation.

(11) An opportunity was found to give this candidate a practical test; that is, to test his ability to distinguish standard signals under service conditions. The test was carried out as follows: A night was selected when the conditions for visibility were good. The candidate was posted at a suitable point with three individuals of normal color perception as controls. Nine shots of various colors were fired from a Very pistol from a point ½ mile distant. The candidate and each of the controls made a record of the color of the shots. The distance was then increased to 1 mile and the procedure was repeated.

Distance ½ mile

Shots fired	Candidate's reading	Shots fired	Candidate's reading
Red	Red.	Red	Red.
Green	*White.*	White	White.
White	White.	White	White.
Green	Green.	Green	Green.
Red	Red.		

Distance 1 mile

Shots fired	Candidate's reading	Shots fired	Candidate's reading
Green	Green.	Red	Red.
Red	Red.	Red	Red.
Green	Green.	Green	Green.
White	White.	White	White.
White	*Green.*		

The three controls recorded the shots correctly in each instance.

(12) This candidate had been passed as having normal color perception by more than one examiner. Even after the defect was detected by the use of the plates, another examiner who had been informed of the nature and the degree of the defect failed to demonstrate it with the Ishihara and the Holmgren tests, certified him as normal with respect to color perception, and stated that he met the physical requirements. When the Holmgren test was properly conducted, however, the defect was at once evident and subsequent testing under service conditions showed that this individual cannot always distinguish a green light from a white light or a white light from a green one when he is deprived of all secondary criteria for a judgment and is forced to make his decision solely on the basis of the chromatic quality of the lights in question. One is forced to conclude that he is incompetent to make any decision of consequence that depends on a recognition of white or green Very flares.

(13) A second case of deuteranopia in which the gross discrepancy of findings on successive examinations was the cause of some embarrassment is quoted in order to illustrate another error of technique in the conduct of the Holmgren test that may vitiate the results. This candidate on preliminary examination read the Ishihara plates in the manner characteristic of the green blind. He was informed that he was disqualified because of color-blindness. Several months later he asked for another preliminary examination and then read the Ishihara and the Stillings plates fairly well. His performance was quite similar to that of the first case referred to. The hesitancy in reading plates 6, 7, 8, and 9 and the difficulty experienced in tracing plates 14 and 15 led to careful checking with the yarns, with the following results:

Red test skein.
- Selected—18.
- Omitted—2.
- Included—1 bright orange yellow and 1 paler orange yellow.
- Performance—confident.
- Direct comparisons—none.

Rose test skein.
- Selected—23.
- Omitted—2.
- Included—3 grays, 2 reds, 2 dark blues, 1 dark purple.
- Performance—hesitant.
- Direct comparisons—with gray and with dark blue and purple.

are no alternative readings for the color-blind, this test cannot be given as quickly as the Ishihara test. On the other hand, the individual with defective color perception has much more difficulty in familiarizing himself with these plates, and even if he has done so, the results of his study of them can be largely nullified by the simple expedient of turning the book upside down. Many normals have some difficulty in reading the plates that involve discrimination between red and brown, red and orange, and green and blue. (Groups VI, VII, IX, XI of seventeenth edition). The test is considered highly effective in determining the true state of color perception, but there seems to be no doubt that the milder types of dichromatism and the anomalous trichromats can improve their reading materially by familiarizing themselves with the test before they come up for the final examination.

151. Jennings test.—Some normals make errors in this test and many of the color-blind go through it without making a mistake. For this reason, the results are not considered conclusive unless confirmed by some other test, except in those cases where the examinee makes errors that are characteristic of the color-blind, such as punching red, brown, or gray for green; green, gray, blue, or purple for rose; or failure to punch green and rose. Any of these errors are conclusive evidence of a disqualifying defect of the color perception. It is necessary to reverse the opinion expressed in Army Medical Bulletin No. 34 that the Jennings test is suitable for the processing of large numbers of candidates. Further experience shows that it is not reliable enough for this purpose and that it is more time-consuming than either the Ishihara or the Stillings. It is believed, however, that the test has a certain field of usefulness in that it can be conducted in a mechanical manner, and in some apparently borderline cases it may afford confirmatory evidence of color-blindness that is surprising in its completeness and its finality. It should be reiterated that a negative Jennings test is of little value in determining the qualifications of a candidate and that significance can be attached to the results only when it is positive; that is, when errors characteristic of the color-blind are made.

152. Holmgren test.—*a.* This is regarded as the basic simple test, for it is possible to obtain more accurate information about the state of the color perception with the yarns than by any other simple method. It is believed that this test if conducted carefully and understandingly will reveal all defects of the color perception that are disqualifying for the military service, and that no individual who is

not actually disqualified will fail to pass the test with ease. From a practical point of view, however, the test has certain limitations that largely destroy its usefulness.

(1) It is tedious and time-consuming. An adequate examination of an alert individual of normal color perception can be done in about 10 minutes. The color-blind case, especially if mild in degree, may require one-half hour or even more. This fact alone makes the test unsuitable for use in the examination of a considerable number of candidates.

(2) In addition to the matter of time, the test does not lend itself to a routine technique of administration as do the plates, and minor variations in technique often produce great discrepancy in the results. Such errors, apparently inconsequential, but actually decisive in their effects, are quite apt to be made unless the examiner has some special knowledge of the common types of defective color perception.

(3) Many of the sets of yarns supplied contain so few skeins and so few of the paler shades apt to be confused by the color-blind that they are practically worthless in the detection of the trichromats and the milder cases of dichromatism. Even a careful examination with one of these abbreviated sets may reveal only the well marked dichromats (red-green blind). The haphazard use of these inadequate sets of yarns is sufficient to account for the fact that in the past we have detected only one in each six color-blind individuals examined.

b. One of these inadequate sets of skeins was recently examined. There are no directions with it. It is made up of 51 skeins, distributed as follows:

Green	13
Red	4
Rose	6
Blue	5
Orange and yellow	11
Lavender	2
Confusion skeins (gray, brown, etc.)	10
Total	51

This set is not only faulty because of the small number of skeins, but also because most of the skeins are the well saturated shades with which the color-blind have the least difficulty. In contrast to this set is a set of 125 skeins that has been used at every opportunity during the past year to examine individuals who have failed to pass the Ishihara or the Stillings test. In every case the results of the plate tests have been confirmed. Some of them made few errors, but

all of them made some errors that were characteristic of defective color perception. This set is composed of the following skeins:

Red	15
Green	27
Rose	10
Blue-purple	13
Orange-yellow	13
Gray	10
Brown, tan, etc	37
Total	125

This set contains too few gray skeins and a disproportionate number of the brown confusion skeins, but even with this obvious defect it has proved to be reliable enough for all ordinary purposes.

c. It is believed advisable before using a set of skeins to examine it critically to determine whether it is suitable for the purpose, for there is little use in using a set that in all probability will not give accurate results. It appears that a good set should contain about 100 skeins. There should be a good assortment of green, of rose, and of red, which must include the lighter shades. The gray skeins should range from very pale gray to very dark gray. It is much better if the gray skeins are not tinted with color; that is, they should be pure neutrals. It is essential that there be such a variety of shades of the different colors that the color-blind individual will find at least some skeins that he is unable to classify. If the set fulfills this requirement, it is necessary only to require the examinee to examine the skeins one at a time and reach a conclusion as to its chromatic quality purely on the basis of his own sensations and without the aid of any secondary criteria.

153. Proposed method of examination.—Put the candidates through either the Ishihara or the Stillings test. Display plates 6, 7, 8, and 9 of the Ishihara in irregular order, and note particularly any difference in the facility with which the two types of plates are read and any discrepancy between the reading of the numeral plates and the tracing of the line plates. Display the Stillings plates in irregular order and show some of them upside down. If the readings in either of these tests are characteristic of the color-blind, a diagnosis of color-blindness is warranted without further examination and the candidate should be disqualified. If the plates are read in the same way with the same facility that the normal read them, appropriate entry ("Normal Ishihara; Normal Stillings") is made on the form and the candidate is reported as physically qualified. If there is any evidence that the plates do not afford

the normal contrast to the candidate, or if because of the discrepancies previously referred to it seems probable that the candidate has studied the plates, a detailed record is made of the readings and the examination is continued with the Holmgren test; a detailed record of the results is made and the report is forwarded, with appropriate recommendations, for the action of the War Department.

An attempt has been made to draw up detailed instructions for the conduct of the Ishihara and the Holmgren tests and to devise forms for the reporting of the results. The ideas expressed have been derived from a number of sources and revisions have been made in the light of knowledge gained from further experience. No claim of finality is made for these instructions; on the contrary, it is anticipated that further revisions will be necessary. They are reproduced here in the hope that they may prove helpful to some examiners and that they may serve as a basis for criticism and for suggestions for improvement. It would seem highly desirable to devise an effective and uniform system for the examination of the color perception and for the reporting of the results, and thereby bring some order and clarity into a situation that at present is confused and obscure.

154. Directions for use of Ishihara test plates.—*a.* The book of colored plates consists of a series of 16 plates (32 in last edition), most of which contain numbers of uniform size and shading, placed in the center or to one side of the center of the circles. Plate 1, containing the figure 12, which is visible to the color-blind as well as to those of normal color sense, shows the size and shading of the other numbers.

b. The candidate is considered to have failed on this test if he does not read the plates in approximately the same way as a person of normal color sense. The examination for color sense is to be conducted only by medical officers found to have normal color sense.

c. To a person of defective color sense, some of the plates seem to show numbers different from those seen by a person of normal color sense, or to show no number at all. Others of the plates appear to contain no number to a person with normal color sense, while the color-blind will read numbers in these plates.

d. The test is made by the examiner holding the book on a table, or in his hands, in good, diffused daylight, between 20 and 30 inches from the eyes of the candidate being tested. The test is made on both eyes together, since for practical purposes defective color sense may be considered as always binocular. The candidate is first asked

to read the figure on plate 1 and is told that the other figures which he is expected to read (plates 2 to 13) are of the same size and type of shading. The other plates, 2 to 13, are then shown to him in turn, allowing him from 2 to 5 seconds to read aloud the figure on each plate—2 seconds for the more alert and intelligent and for those who may have familiarized themselves with the plates previously, and 5 seconds for those who are slower to comprehend. The same time is allowed for plates on which the normal eye can see no figures as for the others, and the examiner is not to signify by tone or motion whether the candidate has read a plate correctly or not. Plates 14, 15, and 16 (see *e* below) may take longer than 5 seconds apiece to explain and trace, but for all the plates the ease with which the plates are read is to be taken into consideration as well as the final answer; thus, some individuals of normal color sense may make out a well shaped 5 and a similar 2 on plates 10 and 11, respectively, but less easily than the figures on the other plates.

e. No numbers are to be read on the three plates, 14, 15, and 16, but they are to be used by having the candidates try to trace a curving line across each plate from the X at the left-hand margin to the X at the right-hand margin, each line being more or less of the same color. These lines should be traced without pressing on the plate, with the rounded wooden end of a penholder, a rounded glass rod, a fine dry camel's hair brush, or other instrument which will not mark the plate. The color-blind may trace a line different from the line traced by the normal, trace no line at all where a line is visible to the normal eye, or trace a line where no continuous line from one X to the other X is seen at all by the normal eye. The examiner is not to name the color of the line to the candidate, but may ask the candidate the color of the line. Before each test care should be taken to see that no telltale line has been left on any of these three plates from previous use.

f. In every case where color perception is found deficient, the results of the test will be recorded on the attached or a similar form, the figures as read by the candidate being placed after the number of each plate, a dash indicating that no figure was read. In the case of plates 14, 15, and 16, the word "red" indicates that a reddish or pinkish line was traced by the candidate, while "blue" indicates that a blue line was traced, and a dash indicates that no line was traced. If the applicant reads both numerals on plates 12 and 13, he will be asked which numeral stands out more distinctly and his answer recorded in the space provided on the blank.

Result in typical case

Plate	Reads	Plate	Reads	Plate	Reads
1	12	7	--------	12	2
2	3	8	--------	13	4
3	5	9	--------	14	Blue
4	2	10	5	15	--------
5	21	11	2	16	Blue
6	--------				

The person whose record is given above is called typically "green-blind" and exhibits the commonest form of color-blindness. If the figures 6 and 2 had been read on plates 12 and 13 respectively, the person would have been called "red blind." All of these responses, except that for plate 1, are different from those given by a person of normal color sense, and yet such a "green-blind" or "red-blind" person can distinguish *some red* and *some green* at ordinary distances and in ordinary weather conditions.

g. If there is a possibility of the candidate's having memorized the correct answers, the order of the plates may be changed by slipping them out of the slots at the four corners and reinserting them at different places. The original order may be determined by reading the small numbers in the margins of the plates with a magnifying glass.

h. The plates must be kept out of direct sunlight and the book should be closed except when actually being read. The book and all directions accompanying it are to be safeguarded from scrutiny by persons not officially responsible for conducting the test. Provided the applicant is found to have normal color vision on this test, no further tests need be used. If color perception is found to be deficient by this test, then the Holmgren yarn test will be given as outlined in the instruction sheet and chart.

Plate number	Examinee reads	Report of Ishihara test of the color perception of------ -- Applicant for-------------------------------
1		Plate No. 12, number -------- is more distinct.
2		Plate No. 13, number -------- is more distinct.
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		
13		
14		
15		
16		

Place---------- ---------------------
Date--------------------------------

Examiner ---------------------------

Medical Corps.

155. Directions for Holmgren (yarn) test.—The test is to be conducted by a medical officer who has normal color perception. Seat the examinee at a table with his back to the window. Place skeins on the table in good diffused daylight—not in direct sunlight. Place the test skein 3 or 4 feet away, so that matches will not be made by direct comparison unless the examinee makes a special effort to do so. Instruct the examinee to take the skeins from the heap one by one and sort them into two piles, the first pile to contain all shades of the color of the test skein, the second pile to contain all other skeins. Go through this procedure separately with the green, the rose, and the red test skeins, mixing the skeins after each sorting. Make no comment on the examinee's selections, but note carefully any erroneous selections, any skeins of the test color that are overlooked, and any skeins that seem to be difficult to classify. (See 2, 3, 4*b*, 4*c* of report sheet.) Then use these skeins as test skeins and go through the procedure as before, entering the color of such additional test skein in one of the blank columns of the report sheet. Spread the skeins out on

the table and instruct the examinee to select the three most brightly colored skeins in the lot.

Report of yarn test of the color perception of.................................
Applicant for...

Test skein used	Green	Rose	Red	
1. Number of skeins of test color selected.				
2. Number of skeins of test color omitted.				
3. Were any skeins other than test color selected? If so, report color and shade of each.				
4. Manner of performance: *a.* Hesitant or confident?				
b. Were any selections made only by direct comparison with test skein? If so, report color and shade of each.				
c. Was classification of any skein changed after direct comparison? Report color and shade of each.				

Selected as brighest colors: (1)........ (2)........ (3)........
Does the examiner agree with this selection? (1)........ (2)........ (3)........
Place................ Date.......... Examiner.....................
Medical Corps.

Section XIX

FIELD OF VISION FOR FORM AND COLORS

156. Peripheral vision.—*a.* In the testing of visual acuity the ability to perceive form is determined in only the foveal region of the retina. This portion of the retina represents a very minute fraction of the entire percipient retina which extends as far forward as the choroid, that is, to the ora serrata, which is about 6 millimeters

from the limbus. Normally, this entire surface of the retina, with the exception of that portion occupied by the structures of the optic nerve, functions, but in a somewhat different manner than at the fovea.

b. Structurally and functionally the fovea and peripheral portions of the retina differ. At the fovea only cones are found, but at a distance of only 0.4 millimeter from center or 1° away from the fovea the rods are more numerous than the cones; 4° away the rods are ten times as numerous and at 10° there are about twenty rods to one cone. Visual acuity, as such, diminishes rapidly away from the fovea. According to Burckardt's formula, the acuity of a point of the retina may be estimated as $\frac{1}{3}$ *n*, *n* being the number of degrees away from the center of the fovea. Other estimates of peripheral acuity have been made which may be at fault, as it is practically impossible to compare by the same test two portions of the retina that are so little alike. "As soon as any test object approaches the proximity (5°–10°) of the fixing area, it exerts so powerful an attraction upon the attention and powers of the central few degrees, that it is almost impossible to resist the impulse to use direct vision" (Lloyd). Binocular fixation, as is obtained with the Stereo-Campimeter, permits more accuracy in determining acuity away from the fovea, fairly accurate findings within the central 20° being obtained. It is evident that we use a surprisingly small portion of the macula for ordinary reading.

c. In the periphery of the retina detection of moving objects is remarkably keen, although fixed objects are not seen with a sharp definition of detail. This function of the retina is one that we do not consider ordinarily, but it is by this function that we are able to orient ourselves in relation to objects within the field of vision. We constantly use the periphery of our retinae in any form of locomotion, walking, driving an automobile, and flying. Further, such function may be considered as a very valuable protective device or warning mechanism.

d. The macula area, where central vision is concerned, is less sensitive to low degrees of illumination, or, in comparison with peripheral points of the retina, is "night blind" normally. One authority has found the most sensitive portion of the retina in recognizing barely luminous points to be between 11° and 13° away from the fovea. This can be determined by observing a barely perceptible star at night; it will disappear on direct fixation, but reappears when the point of fixation is 10° to 15° away from it.

e. We may appreciate the value of peripheral vision by occluding all but the central portion, as looking through a tube of small diameter and attempting to walk across the room. Thus, in a way, the function

of the peripheral portion of the retina is as important as that of the highly developed fovea.

157. Confrontation test.—In determining the extent of the field of vision there are two methods that may be used, but at the same time there are several factors that must be taken into consideration. First, a "rough and ready" method is the confrontation test, or fixation and finger test which, while appearing to be very crude and inaccurate, is very useful when it is done carefully. The examiner stands about 2 feet in front of the examinee, facing him, with a window at one side. The examiner covers his left eye with his left hand and directs the examinee to cover his right eye in a similar manner. Next the examinee is told to fix upon the exposed pupil of the examiner, who in turn fixes upon the examinee's left pupil. The examiner moves his right hand in from the periphery toward the line of fixation, with one or more fingers exposed, keeping his hand at all times as nearly as possible in a vertical plane halfway between him and the examinee. The hand movement is carried out in the vertical, horizontal, and two oblique meridians, and the examiner makes a comparison of the left visual field of the examinee with his own right visual field. The examinee, if his visual field is normal, will identify fingers and finger movements at the same instant as does the examiner, provided the field of vision of the latter is normal. In this manner, an estimate is made of the examinee's left visual field. The examiner and examinee may then change places, and in a like manner the latter's right field of vision may be approximated. This method, quite simple and rapid in its application, will detect any gross defect in the extent of field for form. It has the following advantages: it is quick, requires no special equipment, and enables the examiner to be assured that throughout the test the examinee is maintaining fixation constantly. Its disadvantages are the inability to make accurate quantitative determinations, the impossibility of carrying the test objects (fingers in this case) to the full extent of the normal temporal field (90° or more), and the possibility of overlooking such defects as homonymous and bitemporal hemianopsia. "They may be roughly tested for by telling the patient to look straight at the surgeon, situated as before, both eyes being open. The surgeon holds up both hands, one in each temporal field, and the patient is told to touch the surgeon's hand. If he asks, 'Which one?' he has not bitemporal hemianopsia, since he sees both hands. If he promptly points to one, he should be asked if he sees the other; if he does not, he probably has homonymous hemianopsia" (Parsons).

Where a defect in the visual field is found, or suspected by the fixation test, a more accurate examination using the perimeter should be made.

FIGURE 32.—Perimetric field studies.

158. Perimeter.—The perimeter consists essentially of an arc of 90° or more (more frequently of 180° or more) which may be rotated about a pivot upon which the examinee fixes with the eye being examined. The eye being examined must be situated exactly

before the point of fixation and at a distance equal to the radius of the arc of the perimeter. The examinee must be seated with his back to the light, which should be uniform on the arc of the perimeter regardless of its position. The eye not being examined must be completely screened, as with an eye patch, or the lids may be closed with a strip of adhesive.

With the arc of the perimeter adjusted horizontally the extent of the temporal field for form should be determined by bringing the test object (white in this instance) inward along the arc toward the point of fixation, noting where it is first observed (not where the color is identified) by the examinee (the back of the perimeter arc is marked in degrees away from the point of fixation). At least eight meridians should be investigated, that is, temporal, upward and temporal, directly upward, upward and nasalward, nasalward, downward and nasalward, directly downward, and downward and outward; or, in other words, at intervals of 45°. In each of these meridians the test object should be carried to the fixation point in order to determine the presence of scotomata. The examinee should be cautioned repeatedly to maintain fixation, which is quite difficult, particularly as the test object approaches the point of fixation. Further, the examiner should observe the eye under examination to be sure that fixation is maintained. In outlining the form field, the test object should be gently agitated as the normal limit for each meridian is approached, as the function of the peripheral portion of the retina is primarily to detect moving objects.

159. **Form and color fields.**—*a. Plotting field.*—The form field is plotted upon the perimetric chart which has concentric circles corresponding with degrees on the arc of the perimeter. Where a defect is noted, as many additional meridians as may be necessary must be investigated.

b. Determination of blue, red, and green fields.—After mapping the field for form using the white test object, the extent of the fields for blue, red, and green should be determined, using appropriately colored test objects. "The limit of a field for a color is the point at which, passing from the periphery to the center, the color first becomes evident" (Parsons). This is a point that is difficult to determine even with the help of a very cooperative examinee.

c. Color perception at extreme periphery.—It has been thought, and taught, that the extreme periphery of the retina is color-blind, but by many authorities today this is not considered as being strictly true. "Although it is relatively color-blind, compared to the acuity of the color sense at the fovea, all the colors can be perceived in the periphery in a normal individual if the test object is large enough"

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(Adler). "There is overwhelming proof—that the peripheral vision behaves in exactly the same manner as central vision but with diminished sensitivity. Greater stimuli are required to produce similar responses, but if the stimuli are sufficiently great, the differences disappear, including even qualitative differences so that the fields of vision for colors extend to the extreme periphery" (Parsons). Apparently the size of the test object used for outlining color fields is of the greatest importance, in addition to the intensity of the colors used in test objects. Otherwise, the determination of the so-

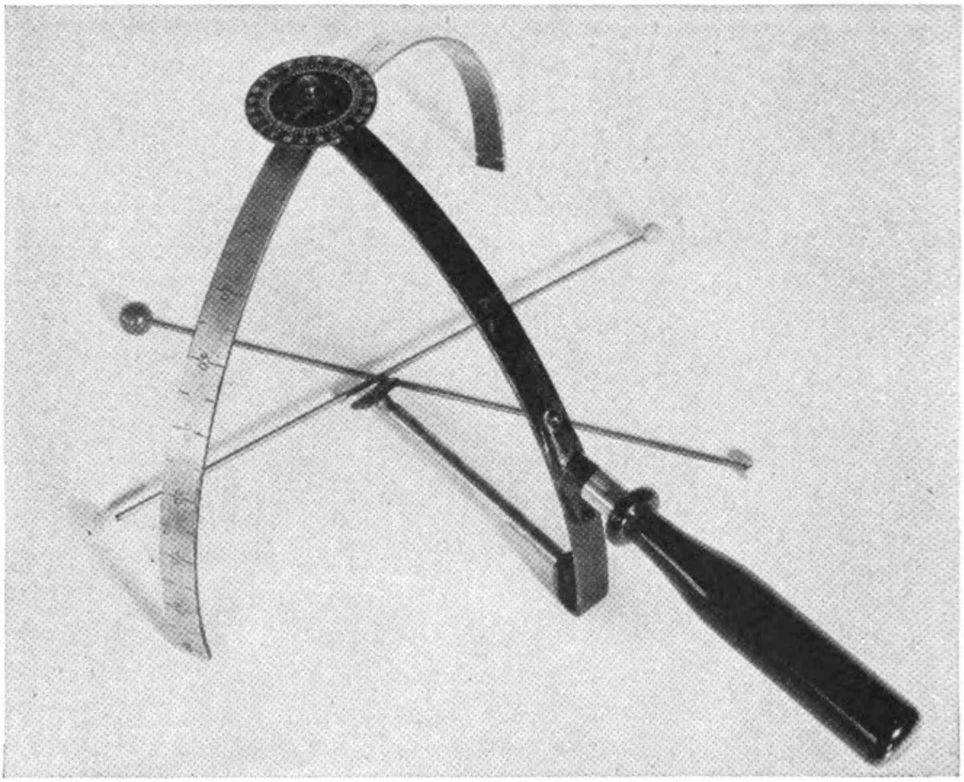


FIGURE 33.—Hand perimeter with spherical test objects.

called color fields, as so frequently conducted, may be of little if any value.

d. Conditions to be observed in color tests and apparatus.—The following is quoted from *Visual Field Studies*, by Ralph I. Lloyd:

> ***Conditions to be observed in Color Tests and Apparatus.***—If color tests are to be used, it is absolutely essential that certain conditions be complied with. The background must be colorless grey which is of the same brightness as the colors used. The tests must be conducted in full "daylight" or the equivalent, which means "standard daylight" obtained by filtering electric light through blue grass to remove the yellow. The test must be done in full illumination and a dark room or low illumination is not permissible because this introduces

the question of dark adaptation whereby "twilight worth" is substituted for "periphery worth." A red and a blue which are of the same brightness by "twilight vision," when observed by the light adapted eye, are peripherally colorless and not of equal brightness. In one case, the dark adapted rods are tested and in full light the peripheral cones. The size of the test discs will be decidedly larger than those we have been accustomed to use, because to obtain peripherally similar colors, the saturation must be lowered. The colors should be invariable, that is, they must pass from the peripheral colorless zone wherein they appear without color, into the zone where they are recognized as true colors, without passing through intermediate phases. They should also be of the same brightness as the background against which they must appear, when observed by the peripheral retina. The test object must be protected from the light and should be replaced at regular intervals.

The use of colored test objects will be referred to again in this section in connection with certain abnormal conditions. The tests of the fields of color are not made in the regular examination of applicants and flyers.

e. Test object.—Going back to the use of the white test object in delineating the field of form; in using the white object, two precautions should be observed; the examinee must be told to indicate when the object is first seen, not to identify it as white; and the test object should be moved back and forth as it is brought in from the periphery. Further, the white test object should be of a certain size. The size of the test object should be noted in degrees rather than its diameter in millimeters. The size of a test object, either spherical or of disc shape, may be estimated fairly accurately by first determining the radius of the perimeter used:

$$\frac{2\times 3.1416\times \text{radius}}{360}=\text{diameter of a }1^\circ\text{ test object.}$$

$$\frac{2\times 3.1416\times \text{radius}}{180}=\text{diameter of a }2^\circ\text{ test object.}$$

$$\frac{2\times 3.1416\times \text{radius}}{74}=\text{diameter of a }5^\circ\text{ test object.}$$

$$\frac{2\times 3.1416\times \text{radius}}{36}=\text{diameter of a }10^\circ\text{ test object.}$$

Or, in other words, the circumference of the circle (of which the perimeter is an arc) divided by 360, the number of degrees in a circle, will be the approximate diameter of a 1° test object. The word approximate is used as in this instance the arc is being used rather than chord to determine the diameter. In outlining the field for form a 1° white test object is ordinarily employed. In plotting the outlines of a scotoma, particularly if it is near the point of fixation, smaller test objects may be used for greater accuracy. The test objects should be illuminated by not less than 7-foot candles.

f. Field for form.—The average normal field for form is approximately as follows:

Out, 90°.
Out and up (45° from horizontal), 62°.
Vertically, 52°.
Vertically and inward (45° from horizontal), 55°.
Inward, 60°.
Inward and downward (45° from horizontal), 55°.
Downward, 70°.
Downward and out (45° from horizontal), 85°.

As a rule, emmetropes and hyperopes have wider fields than myopes. Any contraction of the form field of 15° or more in any meridian disqualifies for flying.

g. Field for color.—The field for blue should be about 10° to 15° smaller than the field for form, and roughly concentric with it; the field for red about 15° less than that for blue; and the green field is usually the smallest, being 10° to 20° smaller than that of the red. As has been shown, the value of color fields as commonly determined is at best questionable. It is not the intention of the writer to advocate abolishing the use of colored test objects altogether, but the student should bear in mind the criticisms of certain authorities before making a definite interpretation of the extent of the various fields for color. Particular attention should be paid to the investigation of the central portion of the field with colored test objects, as central relative scotomata, an acquired color-blindness, may be indicative of toxic amblyopia or retrobulbar neuritis. In such conditions there may be a red-green blindness. In optic atrophy there may be found early a marked contraction of the color fields altogether out of proportion with the contraction of the form field, which shows some degree of contraction.

h. Divisions of visual field.—The visual field, as a whole, may be divided for descriptive purposes as follows (Fuchs):

(1) The central area, from the point of fixation to about 2° around it.

(2) The paracentral zone, from the peripheral limits of the central zone to about 8° on the nasal side and 12° on the temporal side.

(3) The coecal zone, from the limits of the paracentral zone to approximately 25°.

(4) Intermediate zone, from 25° to 60°.

(5) The peripheral zone, beyond 60° in all meridians.

160. Tangent screen and rule.—*a. Use.*—The use of a tangent plane is a recognized and established procedure in the determination of the central, paracentral, and coecal zones of the visual field, for both form and color. For this purpose various campimeters are employed, and in particular the Bjerrum tangent screen or curtain.

Such a device has its limitations in visual field studies, for an attempt to project the entire visual field of a normal eye upon a plane surface is quite impossible. The difficulty lies in the fact that toward the periphery of the field the tangent increases enormously, the limiting value of the tangent of a 90° angle being infinity. For this reason the use of a plane surface in delineating visual fields is limited to the vicinity of approximately 45° which includes the central, paracentral, coecal, and a good portion of the intermediate zones.

b. Advantages.—The method of employing the tangent screen as an adjunct to perimetry is simple and need not be discussed at length. The disadvantages are, as already stated, the limitations of its application to certain zones, and the difficulty experienced with the vary-

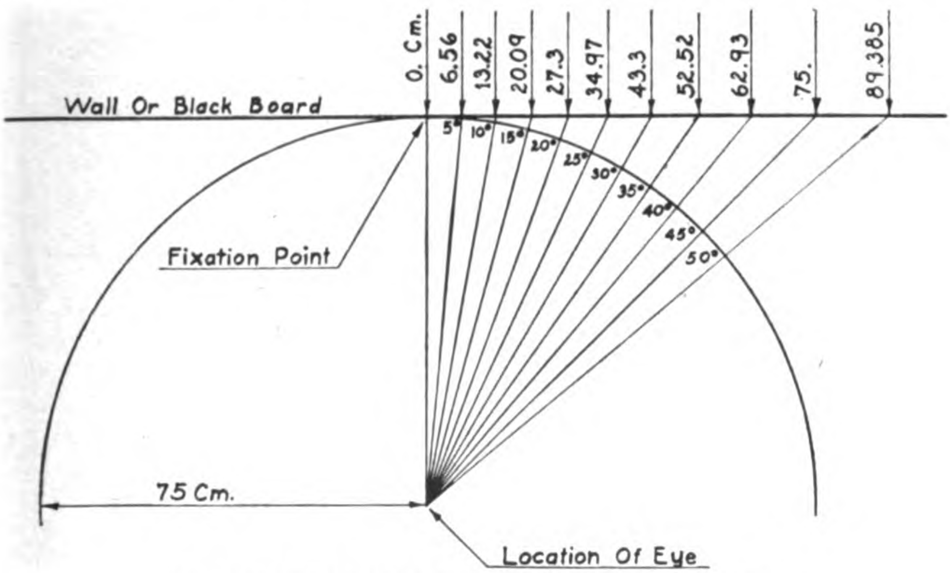


FIGURE 34.—Projection of visual field upon plane surface.

ing size of the retinal image produced by a given test object at different distances from the point of fixation. The advantage of a plane surface is the magnification or enlargement of a scotoma in its projection which assures greater accuracy. Furthermore, the examiner obtains a true and realistic projection of that portion of the visual field which is covered by the screen or plane surface. The ordinary perimetric record does not quite accomplish this result. To interpret the flat perimetric record properly the perimetrist must imagine that he is examining the interior of a hemisphere rather than a plane surface.

c. Equipment.—(1) *Screen.*—A blackboard about 6 feet square, or even smaller, will answer the purpose admirably. Blackboard cloth on an ordinary window shade will serve the purpose if wall space

is not available. For "rough and ready" use the blackboard is not necessary, for a blank portion of wall space may be utilized. The blackboard or wall space may be used at the convenient working distance of 75 centimeters, or at any distance; the value of the tangents, of course, varying with different distances. Any given distance may be halved, quartered, or doubled while using one rule.

(2) *Rule.*—The tangent rule may be made from a yardstick, or a light strip of lath such as is used as a stiffener for the common roller window shade. A more elaborate one may be made from one-eighth inch celluloid, such as is used in making the triangles, protractors, and irregular curves employed by draftsmen. A protractor at one end may be included, which will be found to be very helpful. The values of the tangents should be etched or scratched upon one edge of the rule.

d. Values of tangents.—The exact distance, or values of the various tangents, may be easily computed; but for convenience they are tabulated as follows (for a working distance of 75 cm.):

Degrees	Distance from end of rule (in centimeters)	Degrees	Distance from end of rule (in centimeters)
1	1. 31	26	36. 58
2	2. 62	27	38. 21
3	3. 93	28	39. 88
4	5. 24	29	41. 57
5	6. 56	30	43. 30
6	7. 88	31	45. 07
7	9. 21	32	46. 87
8	10. 64	33	48. 71
9	11. 88	34	50. 59
10	13. 22	35	52. 52
11	14. 58	36	54. 49
12	15. 95	37	56. 52
13	17. 32	38	58. 60
14	18. 70	39	60. 74
15	20. 09	40	62. 93
16	21. 50	41	65. 20
17	22. 93	42	67. 53
18	24. 37	43	69. 94
19	25. 82	44	72. 43
20	27. 30	45	75. 00
21	28. 79	46	77. 60
22	30. 30	47	80. 43
23	31. 84	48	83. 295
24	33. 39	49	86. 28
25	34. 97	50	89. 385

It must be borne in mind that these figures are computed for a working distance of 75 centimeters, and to obtain accurate findings the scale and blackboard are to be used with the examinee's eye at exactly this distance from the fixation point on the blackboard.

e. Procedure.—The examinee should be seated comfortably in front of the blackboard at the proper distance, which may be maintained with a fair degree of accuracy by using the back of a chair as a chin rest. The blackboard should have daylight illumination, that is, should be located before a window in such position that a uniform illumination is assured. The eye not being examined is screened. The tangent rule may be placed against the blackboard as a T-square and adjusted until a point is found directly before the eye being examined, and at this point a dot is made with crayon. This dot is used as a fixation point during the examination.

The test objects are brought in from the periphery of the blackboard toward the fixation point in as many meridians as desired, and where any point of significance is noted, as for example the border of a scotoma, or the limitation of the field for form, a minute crayon mark is made upon the board. The significant points, or marks, in the various meridians may later be connected by lines, and these points and lines measured in degrees from the fixation point by the tangent rule. If a protractor is included with the tangent rule, the exact meridians may be drawn on the board after the examination is completed. Thus we have a fairly accurate outline of the field of vision within 50° of the fixation point, and from it we may arrive at conclusions or make a definite diagnosis just as readily as by studying a record obtained by a perimeter.

f. Record of findings.—When a permanent record of the findings is desired, the tracings on the blackboard may be transferred to an ordinary perimeter form by using the tangent scale, locating points of significance in degrees away from the point of fixation and the exact meridians in which these points are found. If the tangent rule is not provided with a protractor at one end, the various meridians may be determined accurately by again using the measurements on the rule for the tangential values of angles. The horizontal meridian may be determined by measuring the distance from the point of fixation to the floor, and locating a point on the margin of the blackboard at exactly this distance from the floor. A line joining these two points indicates the horizontal meridian. At a point 75 centimeters from the point of fixation on the horizontal meridian, the tangent rule may be placed at right angles to the horizontal meridian; then lines joining the point of fixation and the various points

on the tangent rule indicate the meridians of corresponding degrees (see fig. 33). The same procedure may be adopted for locating the meridians beyond 45° by using the tangent rule at right angles to the vertical meridian, at a point 75 centimeters from the point of fixation. The tangent rule combined with a protractor at one end greatly facilitates this procedure.

g. Test objects.—As to test objects, the following suggestion is offered. Again referring to the tangent rule, we find that the diameter of a 1° test object at 75 centimeters is 1.31 centimeters (approximately, as we are dealing with an arc rather than a chord), and that a 10° test object would be 13.22 centimeters in diameter. But this holds true only when the test object is at the point of fixation on the blackboard. The retinal image of it decreases in size as it is moved

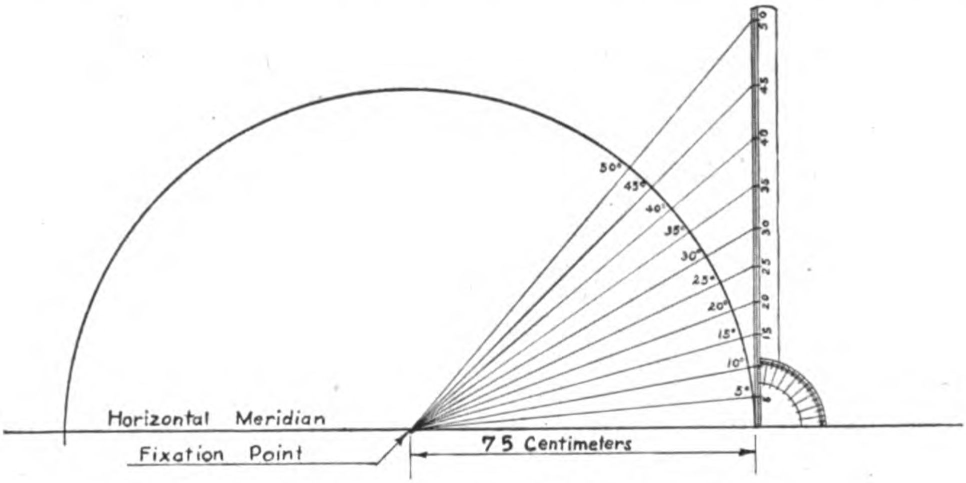


FIGURE 36.—Use of tangent rule to determine meridians.

toward the periphery, and at 45° away from the point of fixation the size of its retinal image has decreased about 33⅓ percent. This fact should be borne in mind and appropriate allowances made. Test objects for form only may be procured in the form of white beads of spherical shape in any required diameter, which may be mounted upon piano wire. Colored beads are available, but here a difficulty presents itself that is hard to overcome, that is, the standardization of the colors. For accurate results in color fields, it is advisable to obtain the discs made of Heidelberg paper.

h. Supplemental use.—Another valuable use of the tangent rule in connection with the blackboard is the determination of the kind and amount of diplopia. For this purpose the blackboard is employed exactly as is the Bjerrum curtain, the red glass before the right eye and the point of illumination being carried outward from the central

point in the six cardinal directions. The point where diplopia occurs is noted by making a small crayon mark upon the board, red crayon being used to indicate the location of the red image, and white crayon for that of the white image. By using the tangent rule, the locations of these positions can be determined in degrees, and the amount of separation noted. The plot formed by the location of the crayon marks may be transferred to a blank form for this purpose, or any perimetric form, with appropriate notations as to whether the diplopia is crossed, vertical, and so on.

161. Classification of defects in visual fields.—*a. General.*—In addition to a constriction of the visual field, visual field defects may be classified as follows (Lloyd):

(1) Scotomata, which may be—
(*a*) Negative.
(*b*) Positive.
(*c*) Relative.
(*d*) Absolute.
(*e*) Coeco-central.
(*f*) Ring.
(2) Hemianopsia, which may be—
(*a*) Homonymous.
(*b*) Heteronymous.
(3) Sectorial defects.
(*a*) Quadranopsia.
(*b*) Hemichromatopsia.
(4) Blindspot scotomata.
(*a*) Seidel's sign.
(*b*) Bjerrum's sign.
(*c*) Roenne's nasal step.

b. Scotomata.—"Scotoma is usually defined as an insular defect in the visual field" (Lloyd). A positive scotoma is one that the patient is aware of, that he sees as a shadow, as may be caused by an opacity in the vitreous near the retina. A negative scotoma is one that the patient is not conscious of, such as that that occurs where there has been degenerative changes in recipient layer of the retina (choroido-retinitis, etc.). Where a positive scotoma is found it is assumed that the perceptive portion of the retina is functioning in part at least. A negative scotoma indicates that a certain area of the retina has lost its funtion.

A relative scotoma is one within which an object is seen as being distorted, or in which the color is not recognized. In an obsolute scotoma the patient does not recognize the object either by form or color.

Coeco-central scotomata, as the name implies, interferes with central vision; the ring types are more peripherally located, the latter are often roughly concentric in outline.

c. Hemianopsia.—By hemianopsia, or hemianopia, is meant a loss of half of the visual field. It may be homonymous, that is, corresponding halves affected, both right halves for example. Or it may

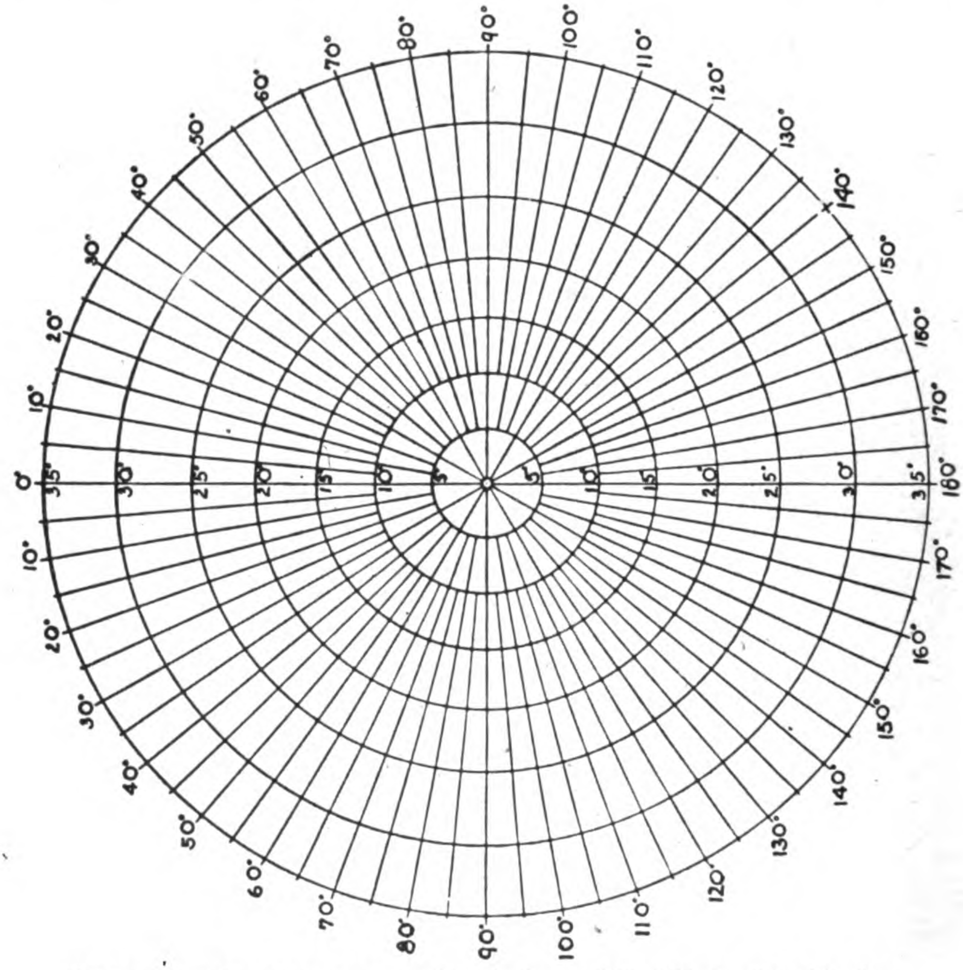


FIGURE 37.—Tangent screen record for findings within 35° of point of fixation.

be heteronymous, which would include the binasal and bitemporal types; "the former points to a lesion crippling both uncrossed bundles which supply the temporal halves of each retina which, in turn, means a loss of each nasal field. To do this the lesion must affect the lateral angle of the chiasm. Bitemporal hemianopsia is the classic sign of pituitary pressure upon the crossed bundles of the chiasm which supply each nasal retinal half which, in turn, implies a loss of each tem-

poral field" (Lloyd). There is a type of hemianopsia classified as altitudinal which is characterized by a loss of function of the upper or lower halves of the retina. Bilateral altitudinal hemianopsia is very rare, but the monocular type is not infrequently encountered (detached retina, optic nerve lesions, etc.).

d. Sectorial defects.—Sectorial defects include losses which are less than quadrants of the visual field, and may be indicative of lesions of

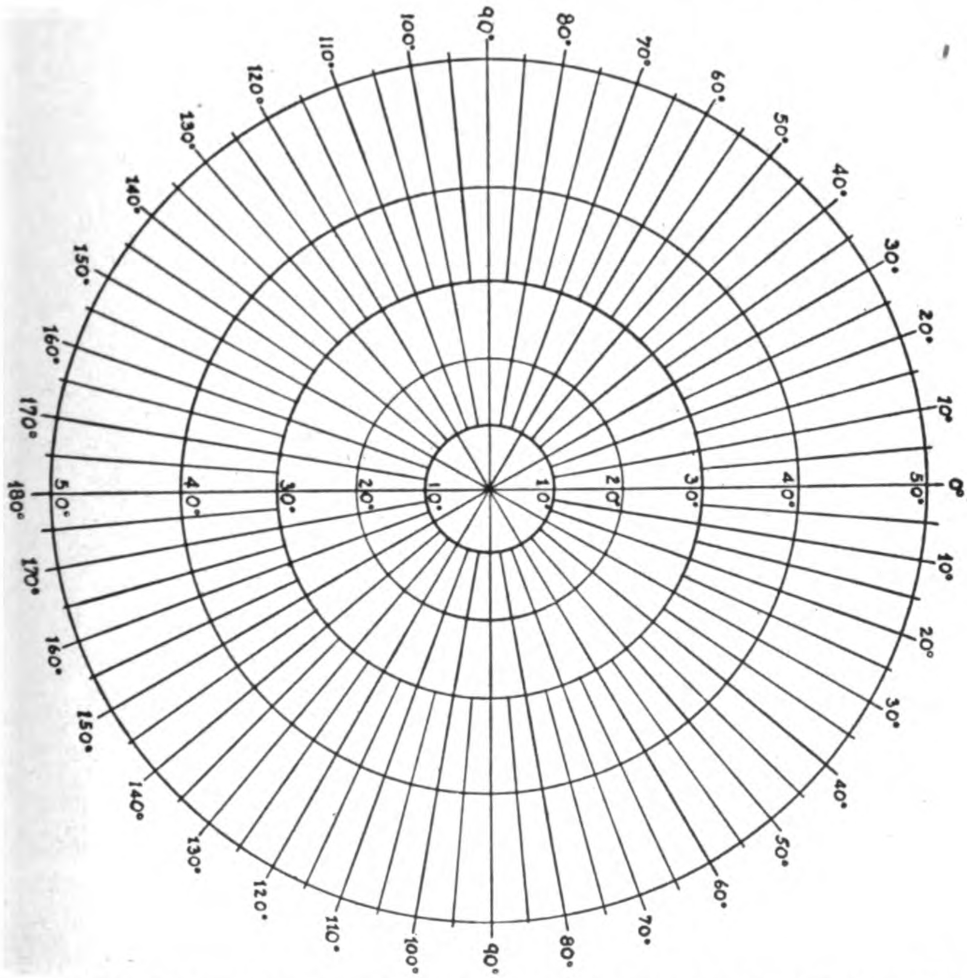


FIGURE 38.—Tangent screen record for findings within 50° of point of fixation. This form may be used for recording diplopia with red glass and tangent screen.

the cortex. By hemichromatopsia is meant a loss of half the field for color only.

e. Blindspot scotomata.—(1) *Seidel's sign.*—"Seidel's sign" is a slender, finger-like scotoma extending from the physiologic blindspot upward or downward and is found in early glaucoma. It usually

requires the employment of quite small test objects with the tangent screen for its detection.

(2) *Bjerrum's sign.*—The Bjerrum sign is a finger-like scotoma extending from the physiologic blindspot above or below, or both, assuming the form of an arc and possibly involving the fixing area. Early it is a relative (color) scotoma, but later it is absolute in glaucoma. The tangent screen, or campimeter, with small test objects, is required for its detection. In addition, it may be found in the senile.

(3) *Roenne's nasal step.*—Roenne's nasal step is a scotoma involving the nasal quadrant, more frequently the inferior nasal quadrant.

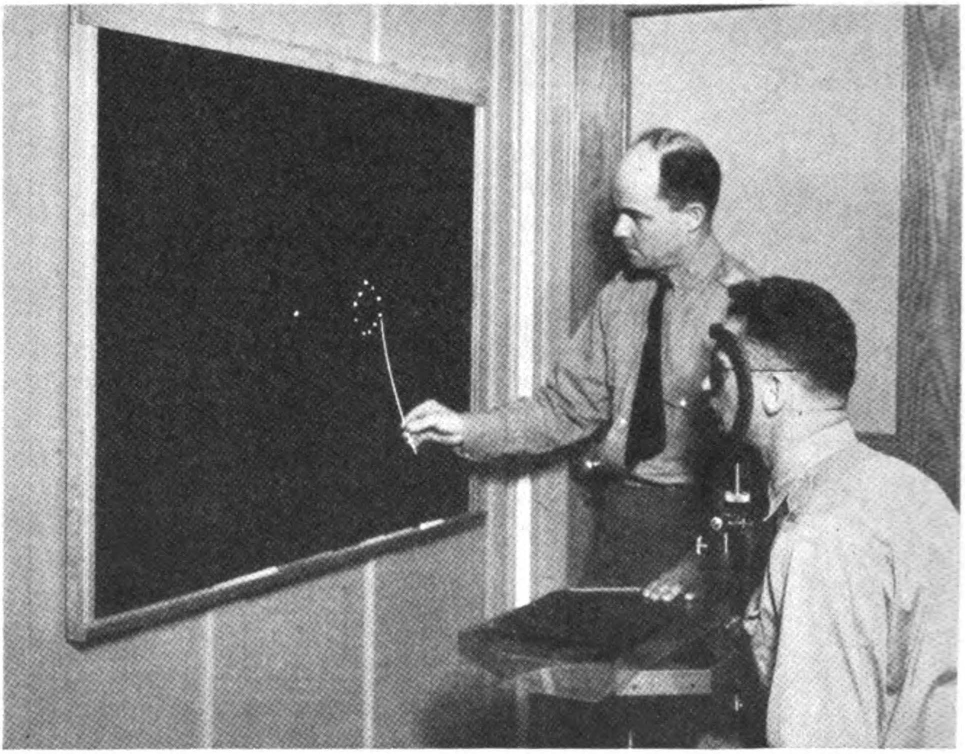


FIGURE 39.—Outlining physiologic blindspot, right eye, on blackboard.

The scotoma is usually roughly right-angular in outline, and its apex advances toward the physiologic blindspot. Such a finding is indicative of glaucoma.

162. Physiologic blindspot.—The physiologic blindspot represents the entrance of the optic nerve into the globe, and therefore corresponds with the anatomical location of the disc in the fundus. Obviously it is within the temporal field of vision of each eye, and is located about 15° away from the macula. Usually it is approximately a little less than 5° in diameter, and its center is situated a little below

the horizontal meridian. As a rule, its vertical diameter is somewhat longer than the horizontal. Clinically its size is important; an enlargement may be indicative of glaucoma, optic atrophy, toxic amblyopia, posterior ethmoidal or sphenoidal sinus disease, arterio-sclerosis, and opaque nerve fibers. An enlargement of the physiologic blindspot is usually found in high degree of progressive myopia.

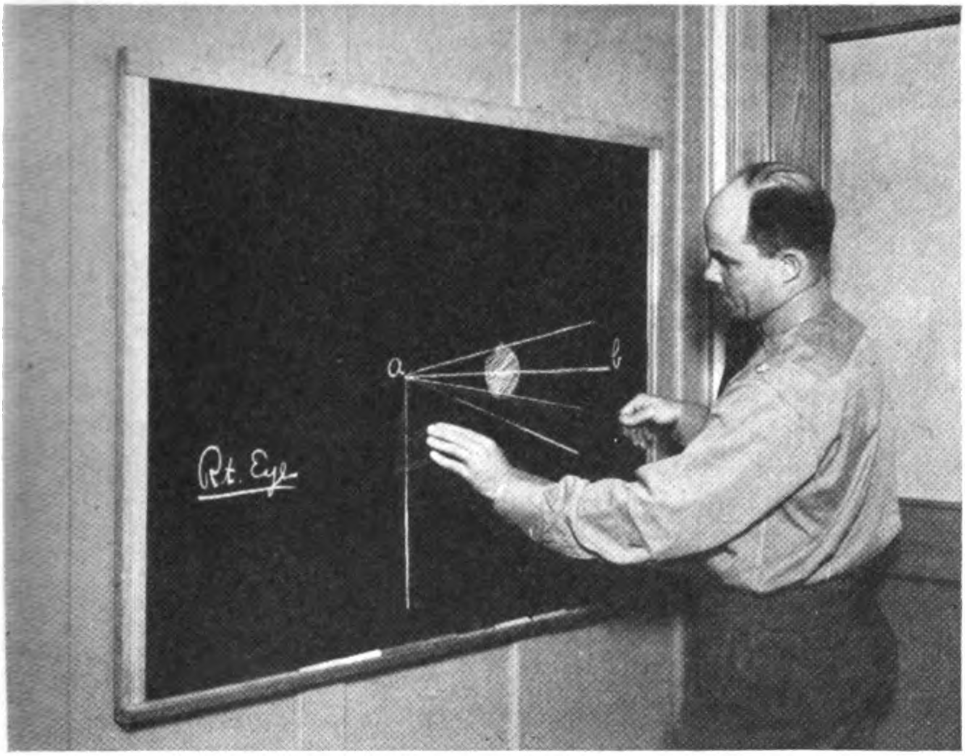


FIGURE 40.—Using tangent rule in locating position and size of physiologic blindspot.

The tangent screen, with small test objects, is more valuable in outlining the physiologic blindspot than is the perimeter. With the latter its location only can be determined. It is suggested that the student outline his own blindspots upon the tangent screen at a distance of 75 centimeters.

The position of the physiologic blindspot may be useful in determining the angle of squint.

SECTION XX

REFRACTION

163. Classification of lenses.—*a.* Before considering methods of quantitatively determining refractive errors, it is advisable that some points in elementary optics be reviewed.

The action of a prism has already been considered, but it must be remembered that a prism will form no image and it has no focus. If two prisms are placed together base to base and viewed from the side, their faces appear somewhat similar to the cross section of a convex spheric lens; the similarity becomes more marked when a comparison is made with a series of truncated prisms placed one above the other, the larger two being base to base. (See fig. 41.) It is easily seen that a lens toward its periphery has the effect of a prism.

b. Lenses may be classified as follows:

(1) *Spherical* (abbreviated as *S*, or *sph*).—In such lenses the curved surfaces represent sections of spheres, and a spherical lens refracts rays of light equally in all meridians. Spherical lenses may be—

(*a*) *Convex* (synonyms plus, positive, collective, magnifying).—Of the convex variety there may be *plano-convex*, *bi-convex*, and *concavo-convex* types. All convex lenses are thickest at the optical center.

(*b*) *Concave* (synonyms minus, negative, dispersive, minifying).—Such a lens may be *plano-concave*, *bi-concave*, or *convexo-concave*. All concave lenses are thinnest at the optical center.

Any spherical lens, on section, may be compared to a series of truncated prisms gradually increasing in strength from the center toward the periphery. In a convex lens the bases of the prisms are toward the center; in a concave lens they are toward the periphery. This comparison enables us to realize the effect a lens has upon parallel rays of light.

(2) *Cylindrical lenses* (abbreviated as *C* or *cyl*).—A cylindrical lens is so termed because it is a segment from a cylinder. There is one meridian of a cylindrical lens in which the lens is of uniform thickness, and this meridian is parallel to the axis of the original cylinder of

which the lens is a segment. This meridian is designated as the axis of a cylindrical lens. A cylindrical lens has no focal point, but has a line of foci, and this line is parallel to the axis. Cylindrical lenses may be concave or convex and may be made with both surfaces curved (bi-convex, bi-concave, etc.). In addition to the designation of the strength of a cylindrical lens, the position of its axis must be noted, when it is prescribed. The commonly accepted designation of axes positions on the spectacle trial frame is 0° to 180° (both these extremes being the same, axis horizontal), increasing in an anticlockwise manner, for each eye, when facing the spectacle trial frame. Consequently, axis 90° is vertical for each eye, but axis 45° is up and out for the left eye, and up and in for the right.

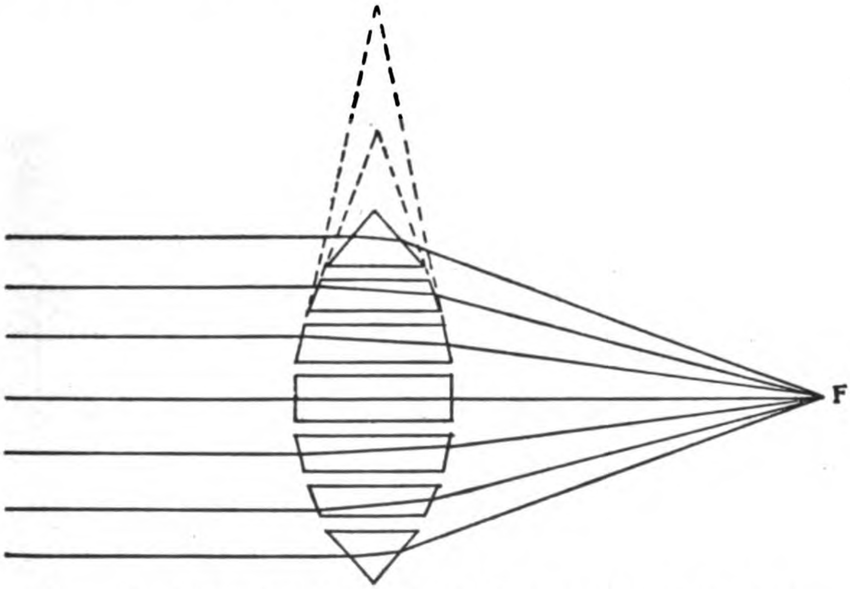


FIGURE 41.—Aggregation of prisms forming bi-convex lens. *F*, real focus.

164. Principal focus—focal length.—*a. Principal focus.*—The principal focus of a lens is the point where parallel rays of light, after refraction by the lens, intersect the axial ray; it is the point, as a matter of fact, where all parallel rays are brought to a focus after being refracted by the lens. In a spherical lens this is a point, in cylindrical lenses the principal focus is a line. In concave lenses, the principal focus is located at the intersection of a backward prolongation of the emerging divergent rays (see fig. 42). The optical center (nodal point) of a simple spherical lens with equal curvature on both sides may be described as a point within the lens equidistant from its two surfaces in the thickest part of a plus lens, and in the thinnest part of a minus lens. It is through this point the axial ray passes.

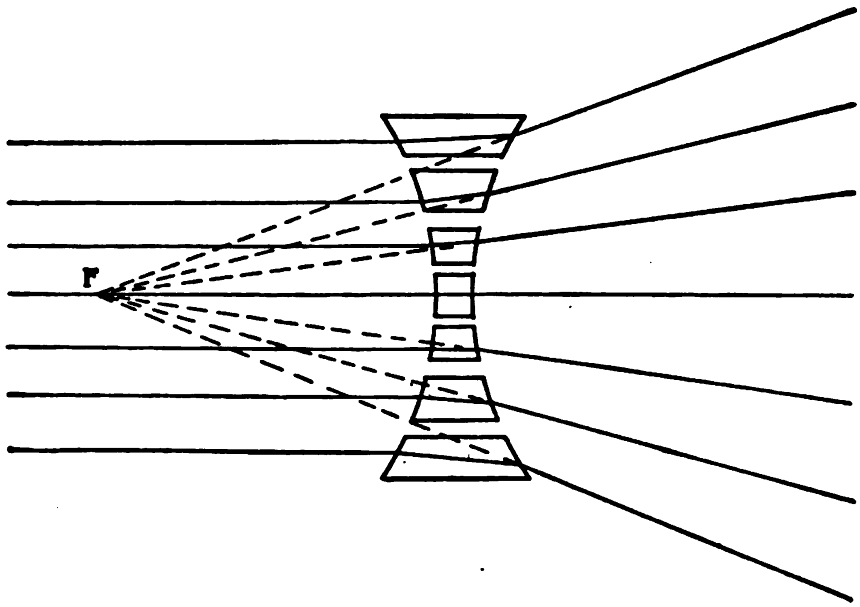
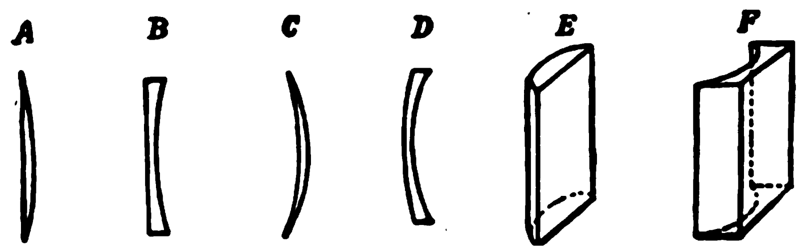


FIGURE 42.—Aggregation of prisms forming bi-concave lens. *F*, virtual focus.



A Plano-convex.
B Plano-concave.
C Meniscus.
D Convexo-concave.
E Convex cylindrical.
F Concave cylindrical (concavo-convex)

FIGURE 43.—Lenses.

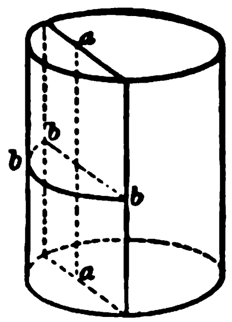


FIGURE 44.—Convex cylindrical lens considered as segment of cylinder.

The optical center and the geometrical center of a lens do not necessarily coincide. The optical center of a cylindrical lens lies within the plane of the axis of the cylinder and is not a point but a line.

b. Focal length.—The focal length of a lens is the distance from the optical center to the principal focus, and this distance determines the strength of the lens. The focal length is measured in the metric system almost universally, and from it the dioptric value of a lens is easily determined. A lens of 1 diopter strength has a focal length of 1 meter, one of 2 diopters has a focal length of 50 centimeters, one of 10 diopters has a focal length of 10 centimeters. Lenses used in the correction of errors of refraction are graduated in one-eighth diopter, expressed decimally; for example, plus 0.12 *S*, plus 1.75 *S*, plus 0.50 *C*, minus 0.87 *S*, minus 2.25 *C*, etc. The focal length of a lens is easily computed, as the dioptric power of a lens is the reciprocal of the focal distance in meters; for example—.

$$\text{Focal length of 1 diopter lens} = \frac{1}{1} \text{ meter.}$$

$$\text{Focal length of 2 diopter lens} = \frac{1}{2} \text{ meter.}$$

$$\text{Focal length of } \tfrac{1}{2} \text{ (0.50) diopter lens} = \frac{1}{0.50} \text{ meter.}$$

c. Conjugate points.—A lens has two principal foci, depending upon the direction from which the parallel rays of light striking a surface come. These are, of course, the same distance from its optical center. So far the effect of a lens on parallel rays of light has been considered. We may now consider rays of light emanating from a point exactly the focal length away from the optical center of a convex lens; such divergent rays, after passing through the lens would emerge parallel to one another and would never intersect. Rays of light from a point at a distance from the optical center of a greater distance than its focal length would eventually converge at a point after passing through the lens. The point from which rays of light diverge and the point at which they converge after passing through such a lens are the conjugate points or foci.

165. Combination of lenses.—*a. Rules.*—Lenses may be combined, as a bi-convex spherical lens is actually in effect two spherical lenses together. There are seven rules regarding the combination of lenses that will enable the student to understand more thoroughly problems in the quantitative estimation of errors of refraction, as well as their correction.

(1) Two spheres of the same sign are equal to a sphere having the strength of the sum of the two; for example, plus 2.00 *S* combined with plus 3.00 *S*=plus 5.00 *S*.

(2) Two spheres of opposite sign are equal to a sphere having the strength of the difference of the two; for example, plus 4.00 *S* combined with minus 3.00 *S*=plus 1.00 *S*.

(3) These above rules apply to two cylindrical lenses when both have the same axis; for example, plus 2.00 *Cx* 90° combined with minus 1.00 *Cx* 90°=plus 1.00 *Cx* 90°; and minus 4.00 *Cx* 180° combined with plus 3.00 *Cx* 180°=1.00 *Cx* 180°.

(4) Two cylinders having the same sign and strength when placed with their axes exactly at right angles make a sphere of the same sign and strength as one of the cylinders; for example, plus 3.00 *Cx* 90° combined with plus 3.00 *Cx* 180°=plus 3.00 *S*.

(5) Two cylinders having same sign but different strengths when placed with their axes crossed at right angles form a sphere of a strength of the weaker cylinder combined with a cylinder equal in strength to the difference between the two and having the axis of the stronger cylinder; for example, plus 3.00 *Cx* 90° combined with plus 4.00 *Cx* 180°=plus 3.00 *S* combined with plus 1.00 *Cx* 180°.

(6) A cylinder combined with a sphere of equal strength but opposite sign is converted into a cylinder of the same strength and sign as the sphere but with an axis at right angles; for example, plus 2.00 *Cx* 90° combined with minus 2.00 *S*=minus 2.00 *Cx* 180°; and minus 1.00 *Cx* 45° combined with plus 1.00 *S*=minus 1.00 *Cx* 135°.

(7) This concerns the result of a combination of two cylinders of opposite sign when crossed with their axes at right angles. Two cylinders, one being plus (*a*) and the other minus (*b*), when crossed with their axes forming a right angle, form a plus sphere of the same strength as (*a*) combined with a minus cylinder of a strength of (*a*) and (*b*) with the axis of (*b*); or they form a minus sphere having the strength of (*b*) combined with a plus cylinder of a strength of (*a*) and (*b*) and having the axis of (*a*). For example, we may consider a plus 2.00 *Cx* 90° combined with a minus 2.00 *Cx* 180°. This would result in a plus 2.00 *S*, combined with a minus 4.00 *Cx* 180°, or a minus 2.00 *S* combined with plus 4.00 *Cx* 90°. The two are optically the same.

b. *Application.*—As will be seen later these rules are particularly applicable in arriving at a conclusion regarding what lenses to place in the trial frame for subjective check on the objective findings of retinoscopy.

c. *Validity.*—The above rules do not hold strictly true except when the lenses are in absolute contact and when ground into a single lens, the two surfaces of which are very close together; that is, a very thin lens. A lens with a plus 10 curve on one surface and a minus 10 on

the opposite will not make a plano lens in effect unless the lens is very thin.

d. Combination of sphere and cylinder.—A sphere and cylinder can be combined on one surface of a lens. Such a combination can be visualized by considering a section taken from an automobile tire or a doughnut. In such an instance, there will be a curvature of a certain radius in one meridian, and in the meridian at a right angle a curvature of a much shorter radius. A section from a rather wide pulley with a shallow groove would be an example of a lens that is minus in one meridian but plus in the meridian at the right angle.

166. Analysis of lenses.—It is important to be able to analyze a lens in order that its optical value can be known. This can be done in a number of ways but the simplest is by "neutralization." First, we may consider a simple spherical lens: If we look at an object in the distance through the lens and move the lens we note the direction of the apparent movement of the object; if it moves in a direction opposite to the movement of the lens it is a plus lens; if the object moves in the same direction it is a minus lens. This is easily accounted for when we remember that a spherical lens on section appears as an aggregate of prisms gradually increasing in strength as the periphery is approached. For example, if we view a point in the distance through a plus lens and the visual axis passes through the lens near the periphery the object will be displaced toward the periphery as we are getting a marked prismatic effect; apex toward the periphery; we then move the lens so that the visual axis passes through a point nearer the optical center, here the prismatic effect is not so great, so the object appears less displaced toward the periphery than before. Then the lens is moved so that the visual axis passes through the optical center of the lens and here there is no displacement of the object. Next the lens is moved laterally in the same direction as before and as the prismatic effect increases toward the periphery the movement of the object toward the periphery becomes accentuated. Consequently, as a plus lens is moved back and forth before the eye, objects seen through the lens appear to move in the opposite direction or "against" the movement of the lens. The reverse is true regarding a minus lens which is made up of an aggregate of prisms apex toward the optical center and base toward the periphery. Therefore when a minus lens is moved back and forth before the eye objects appear to move in the same direction as the movement of the lens, or, as it is usually expressed, "with" the movement of the lens. A lens in this manner may be easily identified as being plus or minus. A quantitative determination may be made by "neutralizing" the lens, by using lenses of opposite sign from the trial lens case. The strength of an unknown lens is

determined by the strength of the lens of opposite sign that, combined with the lens of undetermined strength, causes no movement of an object seen through the two combined. For example, a plus 2.00 *S* is neutralized by a minus 2.00 *S*.

"A cylinder when moved in a direction at right angles to its axis causes a parallactic movement like a convex or concave spherical glass. When moved in the direction of its axis it acts like a plano glass" (Fuchs). In addition, a cylinder causes a certain amount of distortion of objects seen through it. To test for the presence of a cylinder in a lens, two lines crossed at right angles are viewed through it and the lens slowly rotated. In certain positions the lines will appear as being at right angles, but whenever either arm of the cross coincides with the axis of the cylinder the lines will appear at right angles. For example, take a strong plus cylinder (plus 3 or 5) and with its axis vertical (90°) observe a vertical line through it; the vertical line will appear continuous above and through the lens when the line is seen through the optical center of the lens; it will appear displaced toward the periphery if seen through a portion of the cylinder lateral to the optical center, but the displaced line through the lens will be parallel to the line seen above and below the lens. Now rotate the cylinder so that the axis is about 45°, that is, clockwise; now the line, as seen through the cylinder, will appear as leaning in the opposite direction or toward axis 135°. The portion of the line nearest the periphery is farthest displaced. Therefore the line appears to rotate in a direction opposite to the rotation of the cylinder. The reverse is true with a minus cylinder.

To analyze a lens two lines crossing at right angles are observed through it and the lens is moved and rotated until they appear as being continuous with the lines seen beyond the periphery of the lens. Spheres of opposite sign are added until there is no movement of the vertical line; thus the strength of this meridian is obtained. Then the meridian at right angles is neutralized and from the combination of the two the value of the lens is obtained.

First determine the presence of a cylinder, and if such exists, its axis; then neutralize the meridian of the axis, and then the meridian at right angles to its axis; the spherical value and the cylindrical strength with its axis may thus be obtained.

167. Classification of errors of refraction.—*a.* (1) *Emmetropia.*—The normal eye is emmetropic. Quoting Thorington, the following definitions of the emmetropic eye as listed:

An emmetropic eye is one which, in a state of rest (without any effort of accommodation whatever), receives parallel rays of light exactly at a focus

upon its fovea. An emmetropic eye, therefore, is one which, in a state of rest, emits parallel rays of light.

An emmetropic eye is one whose fovea is situated exactly at the principal focus of its refractive system.

An emmetropic eye is one the vision of which, in a state of rest, is adapted for infinity.

An emmetropic eye is one which has its near point consistent with its age.

An emmetropic eye is one which does not develop presbyopic symptoms until 45 or 50 years of age.

(2) *Ametropia.*—An ametropic eye is one which in a state of complete rest does not focus parallel rays of light on the retina. This condition may result from the retina's being too near or too far away from the nodal point (axial ametropia), or due to a defect in the curvature of one or more of the refracting surfaces (curvature ametropia).

(*a*) *Hyperopia* (hypermetropia, *H*, farsightedness).—In such a condition parallel rays of light are not brought to a focus on the retina, with accommodation relaxed, and the focal point is behind the retina; therefore a plus lens is required for its correction. The hyperopic eye must accommodate for infinity, consequently must accommodate more than the emmetropic eye for distances nearer than 6 meters. Hyperopia may be subdivided into the following varieties:

1. *Facultative hyperopia* (*Hf*).—Can be overcome by using the power of accommodation.
2. *Absolute hyperopia* (*Ha*).—Cannot be overcome by accommodative effort.
3. *Manifest hyperopia* (*Hm*).—Is represented by the strongest plus lens the patient will accept.
4. *Latent hyperopia* (*Hl*).—Is the additional amount revealed under a cycloplegic.
5. *Total hyperopia* (*Ht*).—Is the manifest plus the latent hyperopia, and is represented by strongest plus lens required for distinct vision with accommodation completely paralyzed.

Facultative hyperopia becomes absolute after middle life; manifest hyperopia increases with age, while latent hyperopia decreases. With accommodation completely gone $Hm=Ht$.

(*b*) *Myopia* (*M*, nearsightedness).—In such a condition parallel rays of light are brought to a focus before they reach the retina. This may be due to an antero-posterior axis too long for the dioptric system, or to an excess in power of the dioptric system. Accommodative power cannot in any manner come to the aid of the myope;

therefore at distances farther away than his far point all objects are seen indistinctly.

(c) *Astigmatism* (*As*).—In such a condition the dioptric power of the eye is not the same in all meridians. It frequently is the result of a difference in the corneal curvature in different meridians. The anterior surface of the cornea, in such instances, may be compared to a combination of plus sphere with plus cylinder. It is almost invariably a curvature ametropia. Cylindrical lenses are used for the correction of astigmatism. Astigmatism may be—

1. Irregular.—As when the cornea is irregularly distorted, that is, the curvature may not be uniform in a single meridian. The irregular type of astigmatism may be impossible to correct by ordinary lenses.

2. Regular.

(a) *Simple hyperopic* (as corrected by plus *Cx* 90°).

(b) *Simple myopic* (as corrected by minus 1.00 *Cx* 180°).

(c) *Compound hyperopic* (as corrected by plus 2 *S* plus 1.00 *Cx* 90°).

(d) *Compound myopic* (as corrected by minus 2 *S* minus 1.00 *Cx* 180°).

(e) *Mixed astigmatism.*—Hyperopic in one meridian and myopic in another (as corrected by plus 2 *S* minus 3.00 *Cx* 180°).

b. Regular astigmatism may be further classified as to the strength and position of the axis, as—

(1) "*With the rule.*"—As plus cylinder axis 90° or within 45° either side of 90°, or minus cylinder axis 180° or within 45° either side.

(2) "*Against the rule.*"—As plus cylinder axis 180° or within 45° either side of 180°, or a minus cylinder axis 90° or within 45° either side. (These descriptive terms are based on statistical tables on astigmatism. As a rule plus cylinders are required axis vertical or nearly so, and minus cylinders at about axis 180°.)

(3) *Symmetric astigmatism.*—"When the combined value, in degrees, of the meridians of shortest or longest radii of curvature in both eyes equal 180° (no more and no less), then the astigmatism in the two eyes is spoken of as symmetric" (Thorington). For example, *OD* plus 1.00 *Cx* 45°, *OS* plus 1.00 *Cx* 135°; or *OD* plus 0.50 *Cx* 75°, *OS* plus 0.50 *Cx* 105°, etc.

(4) *Asymmetric astigmatism.*—When the combined values, in degrees, of the two axes are not 180°. For example, *OD* plus 0.75 *Cx*

35°, *OS* plus 0.75 *Cx* 90°. Asymmetric astigmatism frequently accompanies facial asymmetry.

(5) *Homonymous astigmatism.*—When the axis of the cylinder is the same in each eye.

(6) *Heteronymous astigmatism.*—One eye with astigmatism "with the rule" and the fellow eye "against the rule."

(7) *Homologous astigmatism.*—Symmetric astigmatism "with the rule."

(8) *Heterologous astigmatism.*—Symmetric astigmatism "against the rule."

(9) *Oblique astigmatism.*—When the axis is neither vertical nor horizontal.

168. Determination of errors of refraction.—*a. Methods.*—There are a number of methods employed to determine quantitatively the existence of ametropia, and these may be divided into two general methods, that is, objective and subjective. Whenever possible, both methods should be employed, one being used as a check on the other.

b. Scheiner method.—One method, more interesting than practical however, is that of Scheiner. It is very rarely used but may be of value to emphasize to the student optical principles involved. Two minute openings are made, a few millimeters apart, through an opaque disc, which is placed in the trial frame before the eye being examined. Accommodation is paralyzed and the pupil dilated to the extent that its diameter is greater than the distance between the two pinholes. Over one of the holes is pasted a bit of red translucent paper. The patient is directed to observe, through these pinholes, a point of light 6 meters away. If the eye is emmetropic there will be but one image of the point of light seen. If ametropia exists there will be two images of the point of light seen (a monocular diplopia), one of which will be red and the other white. Let us suppose the disc is placed before the eye with one pinhole directly above the other, and the upper pinhole is covered with the red paper (or red glass); if the eye is hyperopic, two images will be seen and the red image will be seen below the white (crossed diplopia). The strength of the plus lens required to bring the two images together represents the amount of hyperopia in the vertical meridian. Next the disc may be rotated so that the two pinholes are in the horizontal plane and the amount of hyperopia in this meridian determined. The correction required would be the value of the two cylinders crossed at right angles. In myopia the red image will be seen above the white and the strength of a minus lens required to bring the two images together indicates the amount of myopia, etc.

c. Cycloplegics.—The use of a cycloplegic in estimating errors of refraction enables the examiner to arrive at a definite conclusion, and further, the dilatation of the pupil renders the objective method of refraction much easier. Cycloplegics commonly used in refraction are atropine, in 1 percent solution (in children) and homatropine, 2 percent solution. Cycloplegia may be induced more quickly by scopolamine hydrobromide, 0.2 percent solution, but the possibility of the drug's toxicity must be remembered. The use of paredrine with atropine or homatropine is now widely advocated. Atropine 2 percent, 1 drop, followed in 5 minutes by paredrine 1 percent, and 1 more drop of atropin after 15 minutes will produce satisfactory cycloplegia in 45 minutes for the examination of children. For adults we use 1 drop of 5 percent homatropin followed in 5 minutes by 1 drop 1 percent paredrine; then in 5 more minutes 1 drop 5 percent homatropine and refracting 35 minutes later. It is seldom necessary to use a cycloplegic after the age of 45 or 50 years. Where it is necessary to employ a cycloplegic in patients who are older, one of the weaker drugs, as homatropine, should be used, as the effect may be counteracted by the use of a miotic (eserin, ½ percent solution). Cycloplegics should never be used when glaucoma is suspected.

Homatropine is used more universally for young adults, as its effect is transient, and complete recovery of power of accommodation occurs within 2 days.

d. Retinoscopy.—(1) *General.*—Retinoscopy is the most popular objective method employed in estimation of errors of refraction. It has many advantages; it is quickly learned, is altogether objective, requires little time and only inexpensive apparatus, and is remarkably accurate. The procedure of retinoscopy is simple. Rays of light from a mirror are reflected into the eye being examined, and as the mirror is tilted back and forth the direction of movement of the light as seen in the pupillary area is noted. For practical purposes it is not considered necessary to go into detail regarding the optical principles involved. Either a plane or concave mirror may be used, but with a concave mirror all movements of the spot of light will be in a direction opposite to those when the plane mirror is used. The plane mirror is more commonly used and henceforth any reference to the retinoscope will be to the retinoscope with the plane mirror,

(2) *Simple retinoscope.*—The simple retinoscope is a small circular mirror with a hole through the center, or instead of a hole a minute portion of the "quicksilver" may be removed at the center, through which the examiner observes the reflex in the eye of the patient. A handle is attached to one margin of the mirror. This retinoscope is used in conjunction with a source of light placed

alongside the examinee. The light should be screened, as with an opaque chimney, which has an opening approximately 1 centimeter in diameter on the side facing the examiner.

(3) *Electric retinoscope.*—The electric retinoscope has its own source of illumination placed below the mirror which is set at an angle that reflects the rays of light at a right angle, that is, when the retinoscope is held vertically the rays of light pass forward from the mirror in a horizontal plane.

(4) *Purpose.*—The purpose of retinoscopy is to neutralize as nearly as possible the movement of the illuminated area within the examinee's pupil by the interposition of suitable lenses. The illuminated area is called the "shadow," and when it has no movement with movements of the retinoscope, that is, neither "with" nor "against," it is an indication that the emergent rays of light from the eye of the examinee are brought to a focus at the eye of the

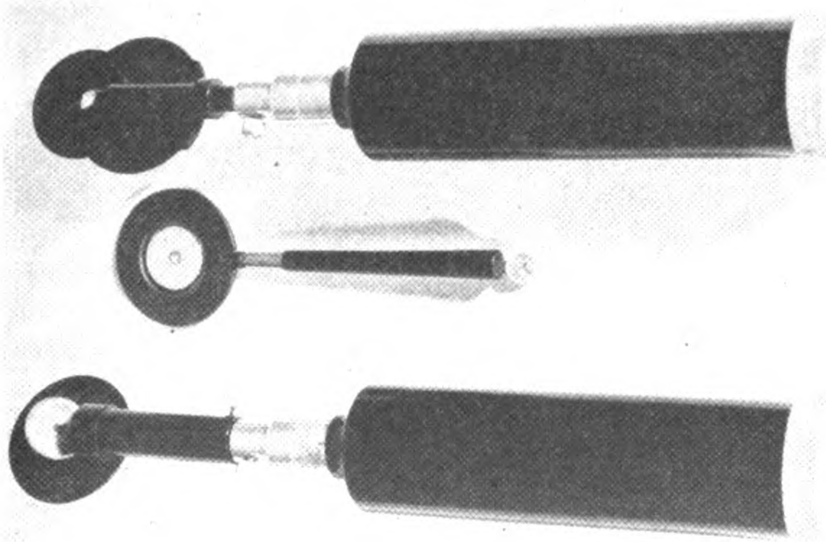


FIGURE 45.—Electric retinoscope, simple retinoscope, and electric ophthalmoscope (May model).

examiner. The lens which accomplishes this neutralization of movement is the lens which will correct the examinee's vision for the distance at which the retinoscope is used.

(5) *Distance.*—It is impractical to attempt retinoscopy at a distance of 6 meters. One meter is a convenient working distance, and is the distance at which the retinoscope is used ordinarily. In addition it is simpler, particularly for the beginner, to make the deduction

for a working distance of 1 meter, which is the focal distance of a lens of 1 diopter. The student must remember that with the retinoscope he is obtaining the correction required by the patient at 1 meter's distance; this correction is 1 diopter more than that required for infinity. Therefore, a correction of 1 diopter deduction must be made for the correction for infinity.

(6) *Method.*—The examinee is seated at a meter's distance in front of the examiner in a darkened room, and the examinee is directed to look fixedly at the forehead of the examiner but not directly at the mirror. A soft, clear light, not too brilliant, is reflected into the eye of the examinee by the retinoscope held firmly before the examiner's right eye with the sighthole immediately before the pupil. The beginner probably will have some difficulty at first in finding the examinee's eye with the beam of light; it is suggested that first it be directed toward the examinee's chest, where it is easily located, and then the spot of illumination slowly raised by tilting the retinoscope until it reaches the eye being examined.

With the retinoscope held in this manner the examiner will obtain a reflection from the pupillary area of the examinee's eye, which will vary in its appearance depending on the amount of illumination used and the refractive error. The periphery of the so-called "shadow" is to be ignored and only the central point noted. If it is circular it is an indication that there is no great difference in the two principal meridians, and very little, if any, cylinder will be required in the correction. A band-shaped reflex or "shadow" is indicative of cylinder being required, and the position of the band indicates the axis. Next the retinoscope is gently tilted back and forth not more than 2 or 3 millimeters or the reflex will be lost. The most common two principal meridians are at 90° and 180°, but they may be at any axis; they are always at right angles to one another. "The axes are indicated by the direction in which the shadow moves when the mirror is tilted. If the mirror is tilted in the vertical meridian and the shadow slides off toward 45°, we know that the two principal meridians are at 45° and 135°. We must shadow these two meridians" (Knighton). The examiner notes the form of illuminated area, its direction of movement in the different meridians, and the rate of movement.

(7) *Axis of cylinder required.*—If the mirror is tilted vertically it is rotated about its horizontal axis, and if it is tilted laterally it is rotated about its vertical axis. The axis about which the mirror is tilted indicates the axis of the cylinder required.

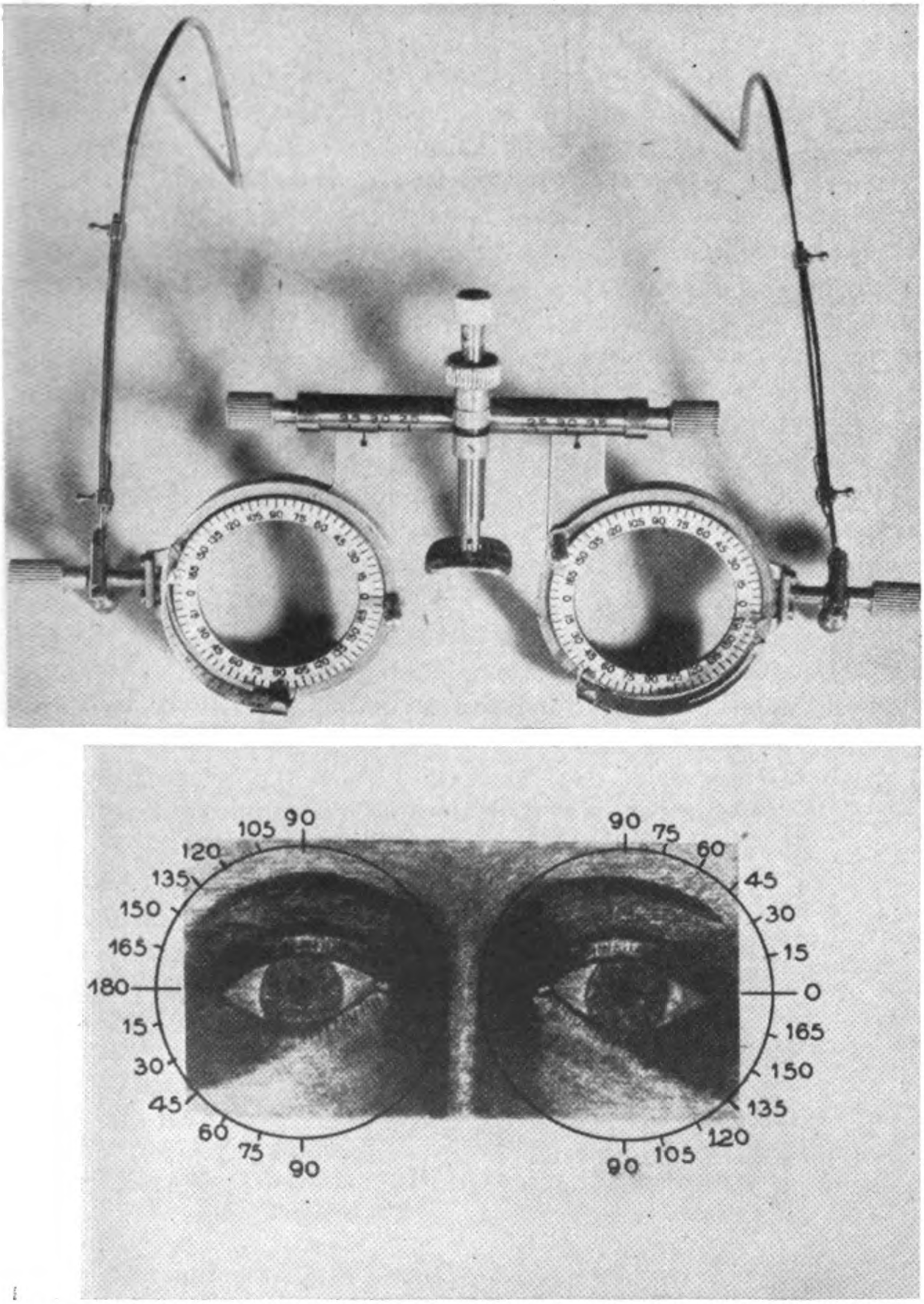


FIGURE 46.—Spectacle trial frame and diagram showing positions of axes of cylindrical lenses.

(8) *Type of lens.*—A movement of the illuminated area with the movement of the retinoscope indicates hyperopia, emmetropia, or myopia of less than 1 diopter, and a "with" movement is neutralized by a plus lens. A movement "against" the movement of the retinoscope indicates a myopia greater than 1 diopter. An "against" movement is neutralized by a minus lens. Spheres are used to neutralize the movement in the two principal meridians.

(9) *Point of neutralization.*—The exact point of neutralization is difficult to obtain, consequently the point of reversal is recorded. The weaker sphere that causes a reversal of the movement is recorded as the end point. Where a movement "against" is found, it may be overcorrected by a minus lens that is obviously too high, thus giving a movement "with," and then plus lenses added until the first movement against is noted. The value of the combination of the two lenses is noted and recorded.

(10) *Recording findings.*—(*a*) *Method.*—It is suggested that the beginner use an inverted letter T in recording his findings. He may imagine that the cross bar indicates the horizontal meridian and the upward stroke the vertical meridian. If the inverted T is considered as being placed before the examinee's face, the right angle to the left side of the examiner will indicate the findings of the right eye and the right angle on the right will indicate the findings of the left eye.

(*b*) *Examples.*

1. First consider one eye alone. With the retinoscope at 1 meter there is a "with" movement in all meridians. Place a plus 1.00 *S*, in the trial frame, before the eye and movement is still "with". Replace the plus 1.00 *S* with a plus 1.25 *S;* the movement is still "with." Gradually increase the strength of the sphere until a reversal is obtained. Suppose in this case a reversal in all meridians is obtained first with a plus 2.00 *S*. The findings are then recorded thus:

$$\begin{array}{c|}+2.00\\ +2.00\\ \hline\end{array}$$

and, since 1 diopter must be deducted for correction for infinity—

$$\begin{array}{c|}+2.00\\ +2.00\\ \hline\end{array} -1= \begin{array}{c|}+1.00\\ +1.00\\ \hline\end{array} = OD+1.00\ S \text{ for infinity}$$

In this instance two cylinders of the same sign and strength crossed at right angles are dealt with (rule (4) in combination of lenses).

2. Next consider several other types of cases, as for example—

a.

$$\begin{array}{c|c} +3.00 & +4.00 \\ +3.00 & +4.00 \end{array} -1= \begin{array}{c|c} +2.00 & +3.00 \\ +2.00 & +3.00 \end{array} = \begin{array}{l} OD\ +2.00\ S \\ OS\ +3.00\ S \end{array}$$

b.

$$\begin{array}{c|c} +3.00 & +2.00 \\ +4.00 & +2.50 \end{array} -1= \begin{array}{c|c} +2.00 & +1.00 \\ +3.00 & +1.50 \end{array} = \begin{array}{l} OD+2.00\ S \\ \quad +1.00\ Cx\ 90^\circ \\ OS+1.00\ S \\ \quad +0.50\ Cx\ 90^\circ \end{array}$$

Here is an application of rule (5) in combination of lenses. For the right eye there is a reversal with vertical tilting of the retinoscope (axis 180°) with a +3.00 *S*, and a reversal with horizontal tilting (axis 90°) with a +4.00 *S*. In this case, a +3.00 *Cx* 180° combined with +4.00 *Cx* 90° is actually dealt with. This is equivalent to +3.00 *S* (which is +3.00 in all meridians) combined with a +1.00 *Cx* 90° (the meridian that requires a total of +4.00 *S*).

c.

$$\begin{array}{c|c} -1.00 & -1.25 \\ 0 & -0.25 \end{array} -1= \begin{array}{c|c} -2.00 & -2.25 \\ -1.00 & -1.25 \end{array} = \begin{array}{l} OD-1.00\ S-1.00\ Cx\ 180^\circ \\ OS-1.25\ S-1.00\ Cx\ 180^\circ \end{array}$$

d.

$$\begin{array}{c|c} +0.50 & +0.75 \\ +0.75 & +0.75 \end{array} -1= \begin{array}{c|c} -0.50 & -0.25 \\ -0.25 & -0.25 \end{array} = \begin{array}{l} OD-0.25\ S-0.25\ Cx\ 180^\circ \\ OS-0.25\ S \end{array}$$

e.

$$\begin{array}{c|c} +1.75 & +2.00 \\ +0.25 & -0.25 \end{array} -1= \begin{array}{c|c} +0.75 & +1.00 \\ -0.75 & -1.25 \end{array} =$$

OD +0.75 *S* −1.50 *Cx* 90°, or −0.75 *S* +1.50 *Cx* 180°
OS +1.00 *S* −2.25 *Cx* 90°, or −1.25 *S* +2.25 *Cx* 180°

In this instance there is a mixed astigmatism; rule (7) in combination of lenses applies in this case, as in the retinoscopic findings a plus cylinder in one meridian and a minus cylinder in the other are dealt with.

f. In oblique astigmatism the inverted T has to be modified; it is suggested that in such instances a right angle for each eye be used, the arms of which indicate the principal meridians, as—

$$\begin{array}{c} +2.00 \\ +3.00 \end{array} \times \begin{array}{c} +2.50 \\ +3.25 \end{array} -1= \begin{array}{c} +1.00 \\ +2.00 \end{array} \times \begin{array}{c} +1.50 \\ +2.25 \end{array}$$

$$= \begin{array}{l} OD+1.00\ S+1.00\ Cx\ 135^\circ \\ OS+1.50\ S+0.75\ Cx\ 75^\circ \end{array}$$

(11) *Subjective check.*—From the findings that have been determined by retinoscopy, the examiner has the data necessary for the subjective check. If the cycloplegic is complete and the retinoscopy done carefully the correction for infinity as found by retinoscopy should obtain an acuity of 20/20 or better, that is, with accommodation paralyzed. There are several factors that necessitate a subjective test immediately after retinoscopy, particularly the exact determination of axis of a cylinder as well as strengths of both sphere and cylinder. In the subjective examination the formula will be found to be somewhat less, as to spherical value (less plus or more minus). The addition of a minus 1.00 *S* to the findings at 1 meter corrects for infinity; with the Snellen test types at 6 meters there must be brought into play either one-sixth diopter of accommodation, or one-sixth diopter added to the formula. Consequently, when the patient is fully corrected for a distance of 6 meters he may be slightly overcorrected for infinity. One quarter diopter sphere is usually subtracted from the trial lens for 6 meters distance for actual correction for infinity.

(12) *Subjective examination.*—A subjective examination should follow retinoscopy immediately. This is of particular value where there is a cylindrical correction, and both the strength and axis of the cylinder should be checked carefully. Each eye should be checked separately.

(13) *Checking axis of cylinder.*—In checking the axis of the cylinder, it is shifted quickly from one side to the other (about 15° to 20°) from that found by retinoscopy, and the degree of rotation gradually decreased until maximum vision is obtained. The position of the axis of a cylinder may be confirmed by employing a stronger cylinder than that found by retinoscopy. This naturally will result in some blurring of vision, but is of value as the axis may be shifted back and forth until all vertical lines appear as vertical to the patient, then the stronger cylinder may be replaced by one of the strength as found by retinoscopy.

(14) *Astigmatic dial.*—The "clock face" or "sunburst" (astigmatic dial), consisting of radiating lines is of value in determining both the axis and the strength of a cylinder. This is based on the fact that in astigmatism lines in different meridians are not seen with equal distinctness. The meridian of the eye which corresponds to the most sharply defined lines, or the blacker, is the meridian of the greatest ametropia, and the median at right angles to this is the most nearly emmetropic. The axis of the cylinder required will be at right angles to the meridian of the darkest lines. The greater number of test cabinets and charts for visual acuity have an included astigmatic dial or chart.

e. Stenopaeic slit.—The stenopaeic slit may be used for the subjective determination of astigmatic errors of refraction, with test types at 6 meters, or in connection with the astigmatic dial. The stenopaeic slit consists of an opaque disc with a very narrow (½ to 1 mm.) slit in one diameter. The slit is of the same size as the trial lens and may be placed in the rotating cell of the trial frame; the slit, before the eye being tested, is rotated until it reaches the meridian where clearest vision is obtained; the sphere is then changed until 20/20 is seen, and a notation is made of the strength required for this meridian. Next the disc is rotated exactly through 90°, and spheres added until 20/20

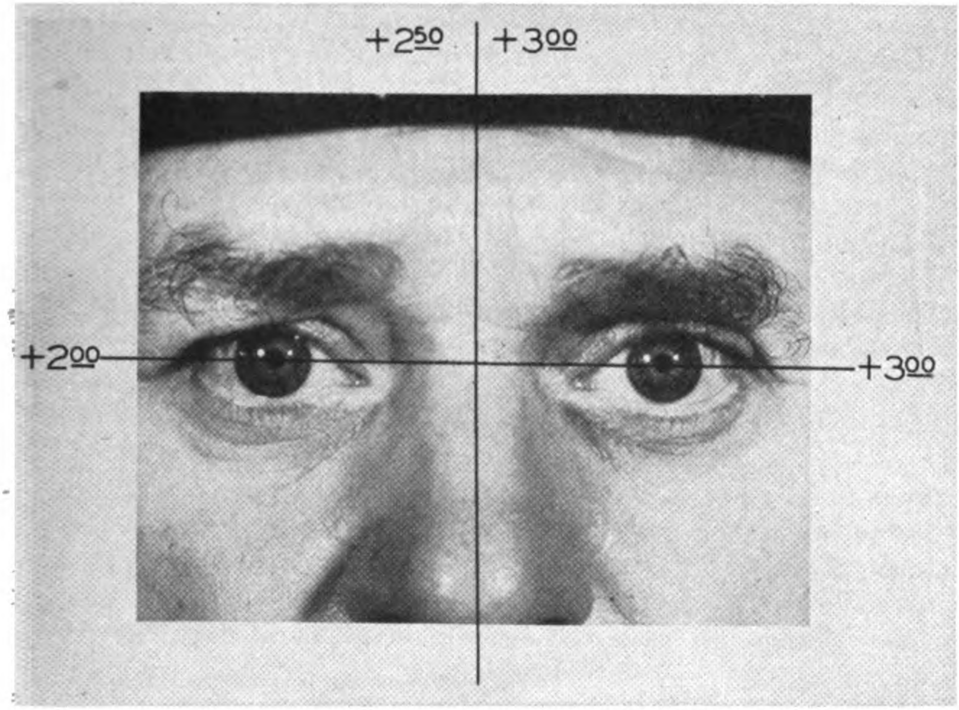


FIGURE 47.—Retinoscopic findings.

vision is secured. The total correction may be estimated fairly accurately by these two findings. For example, with slit placed vertically the patient reads 20/20, and with the slit horizontal he only reads 20/40. But with a plus 1.25 *S* before the slit (placed horizontally) he reads 20/20. We may conclude that his correction is plus 1.00 *Cx* 90°. The slit is used at right angles to the axis of the cylinder required. The slit may be of value in determining accurately the position of the principal meridians.

f. Cross cylinder.—The cross cylinder is used to a distinct advantage in finding the strength and axis of a cylinder where such is indicated.

The method of its use is altogether subjective. The cross cylinder, as its name implies, is a compound lens made up of two cylinders of opposite sign with axes crossed at right angles; these two cylinders are of the same strength and, of course, are equivalent to sphero-cylinder combination. For example, a minus 0.12 *Cx* 90° combined with a plus 0.12 *Cx* 180° would be equivalent to a minus 0.12 *S* combined with a plus 0.25 *Cx* 180°. Cross cylinders are used in strengths of 0.12 to 1.00 diopters; more frequently the middle strengths are used. The lens is mounted in a circular frame to which a handle is attached radially at a midpoint between the two principal axes, and is not placed in a cell of the trial frame but held by the handle before it. By rotating the handle 180° about its own axis, the examinee can make a decision as to the better of the combination. For example, the handle may be held obliquely up and out so that the cross cylinder amounts to a plus *Cx* 90° and minus *Cx* 180°. By flipping it over (rotating the handle), it becomes minus *Cx* 90° and plus *Cx* 180°.

In using the cross cylinder for a determination of cylindrical strength the lens is held with first one and then the other of its principal axes coinciding with the axis of the cylinder already placed in the trial frame, or coinciding with any axis in regard to which the presence or absence of astigmatism is to be determined. A notation is made as to which position gives the best acuity, although either of the two may blur the test types to some extent. The position of the cross cylinder selected by the examinee is an indication of the change to be made in the cylinder in the trial frame, that is, an increase or decrease in strength. "Thus if the trial frame contains a minus cylinder with its axis at 60°, and the preferred position of the cross cylinder is that in which its minus axis is at 60°, the strength of the cylinder in the trial frame should be increased. The reverse would be true if the preferred position of the cross cylinder were that in which its plus axis was held to correspond with the axis of the minus cylinder in the trial frame. And vice versa, if the cylinder in the trail frame is a plus cylinder" (Crisp). In instances where the astigmatism is practically vertical or horizontal this determination may be somewhat at fault, as regards an exact determination, as the examinee may select the position of the cylinder which causes a vertical rather than horizontal distortion of the test letters.

In the description of the use of the cross cylinder for the location of the exact axis required, the following is quoted directly from Dr. Crisp:

> The cross cylinder test for axis is at first sight rather more complicated. It is based on the principle that two cylinders of like denomination, superimposed with their axes at an acute angle with one another, form a new cylinder of

different strength, whose axis is somewhere intermediate between the two axes of the separate lenses.

If we lay a plus 1.00 D. cylinder upon another plus 1.00 D. cylinder, so that the two plus axes are 45° apart, the combination will be equivalent to a plus 0.25 D. sphere combined with a plus 1.50 cylinder, whose axis is exactly half way between the two separate axes. If the two cylinders are of unequal strength, the new axis will be nearer the axis of the stronger individual cylinder.

Suppose now that we have in the trial frame a minus 1.00 D. cylinder with its axis at 90°, and we wish to determine whether the axis should be changed in either direction from the exactly vertical position. A cross cylinder—say minus 0.50 sphere combined with plus 1.00 cylinder—is held with its two axes at 45° with the axis of the cylinder in the trial frame. If the minus axis of the cross cylinder is at 45° there is produced before the patient's eye a new cylindric effect at an axis midway between 90° and 45°, that is at 67½°. If, on the other hand, the minus axis of the cross cylinder is at 135°, the resulting minus cylinder has its axis midway between 90° and 135°, or at 112½°. If the axis of the patient's astigmatic error lies nearer 45° than 135°, he may find the test type blurred by either position of the cross cylinder, but the blur will be less pronounced when the cross cylinder is held with its minus axis at 45° than when it is held with its minus axis at 135°. The change in position of the cross cylinder is again made by a simple rotation of the handle between the examiner's thumb and index finger.

The patient having expressed a preference as between the two positions of the cross cylinder, we must move the minus axis of the lens in the trial frame toward the preferred position of the minus axis of the cross cylinder. We have no exact indication as to how far this change of axis should be carried. But the cylinder in the trial frame is moved arbitrarily any distance in the indicated direction, and the test with two positions of the cross cylinder is again made, only this time the axis of the cross cylinder must be at 45° with the new position and not with the original position of 90°.

At every new test, it is important that the cross cylinder shall follow the changed position of the cylinder which is in the trial frame. We may have shifted the position of the cylinder in the trial frame either too far or not far enough. In either case the next test with the cross cylinder will tell us whether to go farther or to come part way back. But as we gradually diminish the range of alteration in the position of the cylinder in the trial frame, we shall at last reach a position in which the patient is unable to read any more or fewer of the letters with one position of the cross cylinder than with the other. We have then reached the desired point and have determined the correct axis required by the patient, subject to any change which may be obtained in checking up the strength of sphere and cylinder.

Like all other astigmatic tests, this one is more likely to be successful if the accommodation is relaxed and, therefore, if whatever spherical lens is in the trial frame is so strong a plus or so weak a minus as barely to allow the patient to obtain his full visual acuity. Further, the patient must base his comparison of the two positions of the cross cylinder upon a study of the lowest line of letters which he can even partially or imperfectly read. It must also be remembered that the vision with the cross cylinder before the eye is very commonly less distinct than without it, and especially that at the final axis obtained the cross cylinder blurs the vision equally in both positions of the test.

For eyes with good visual acuity the test for axis may usually be made satisfactorily by means of the cross cylinder of minus 0.25 sphere and plus 0.50 cylinder. For the earlier stages of testing a high error, or sometimes as a check in unusually variable cases, the minus 0.50 sphere combined with plus 1.00 cylinder is useful. The minus 1.00 sphere combined with plus 2.00 cylinder is of value in relatively amblyopic cases.

In making the cross cylinder tests, the patient should usually not be asked whether he sees better with the cross cylinder or without it. What is needed is the choice between its two positions. Furthermore, there is almost never any advantage in checking the cross cylinder test for axis by means of the old-fashioned method of turning the cylinder in the trial frame in either direction until the patient decides that the vision is blurred.

g. Fogging method of refraction.—In instances where the amplitude of accommodation is obviously within a narrow range, as with presbyopes, the "fogging" method of refraction may be resorted to. This is purely subjective and does not require the use of a cycloplegic, therefore is particularly adaptable to those who are past midlife, or those patients in whom the use of a cycloplegic is contraindicated. It is not so satisfactory in young adults, and its use is usually limited to patients who are over 45 years of age. This method simulates a cycloplegia by the induction of ciliary relaxation by the interposition of a plus sphere which is obviously of sufficient strength to overcome any ciliary muscle power the eye might otherwise use when looking at a distance of 6 meters. The eye being examined is rendered artificially myopic temporarily by the strong plus sphere causing the ciliary muscle to relax. This method is especially applicable in cases of hyperopia, hyperopic astigmatism, and mixed astigmatism. As an example, the patient is 47 years of age and has a visual acuity of barely 20/20, obviously with effort. A plus 4.00 sphere is placed before the eye examined and the test types at 6 meters are illuminated. His vision is blurred or fogged, and in an effort to see more clearly his accommodation will relax. Minus spheres, gradually increasing in strength, are placed before the plus 4.00 *S*, until he can read 20/20. Suppose in this instance the strength of minus sphere required is 2.50. He is hyperopic to the extent of 1.50 diopters (plus 4.00 *S* combined with minus 2.50 *S*=plus 1.50 *S*).

h. Strength and axis of cylinder.—Where there exists an astigmatism, the astigmatic dial, the stenopaeic slit, and the cross cylinder may be used in testing strength and axis of cylinder required, after maximum acuity has been obtained by spherical correction alone. The stenopaeic slit may be utilized, as the two principal meridians may be located and each fogged separately.

i. Manifest method.—In the manifest method, lenses are added until normal vision is obtained without the induction of ciliary relaxa-

tion. Therefore, it is not applicable to hyperopes under 45 years of age. Where myopia is suspected in markedly defective visual acuity, the use of the pinhole disc is of value, as with it vision will be greatly improved, if the visual defect is due to the myopia alone. The manifest method should be restricted to patients who are over 45 years of age, and in some instances, cases of compound myopia in young adults where a cycloplegic is contraindicated. "The rule is to employ the strongest plus lenses or the weakest minus lenses which will give normal vision" (Thorington).

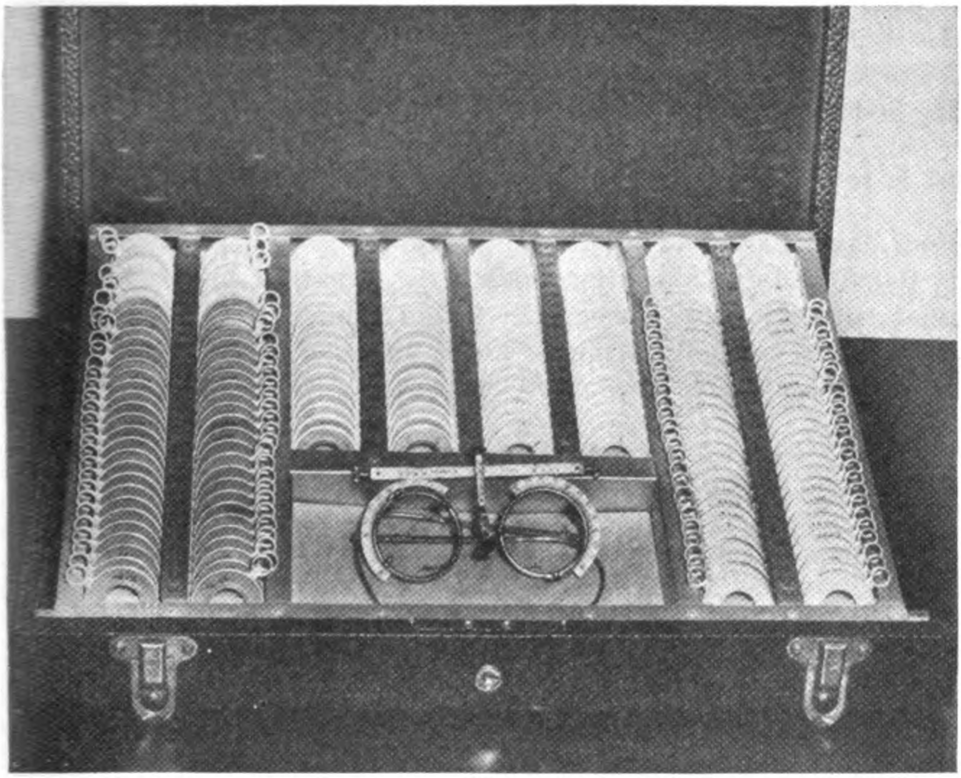


FIGURE 48.—Trial lens case.

j. Post-cycloplegic test.—The post-cycloplegic test (indicated where glasses are to be prescribed) should be done after complete recovery of the power of accommodation. This will be 3 to 4 days after retinoscopy where homatropine has been used, and by the findings at this time we are guided as to the tolerance of the patient for his full correction. It will be found as a rule young adult hyperopes will not accept the full spherical correction as determined by retinoscopy and confirmed subjectively with cycloplegia. In the young hyperope there has been a habit acquired of correcting, either wholly

or in part, his refractive error, and this habit will not be broken easily.

(1) *Hyperopes.*—In hyperopes it is suggested that the full correction (as determined previously) be placed on each eye and the two eyes checked together. If this results in blurring, add weak minus spheres (minus .12) to each eye until normal vision is obtained (20/20), and the strongest sphere giving 20/20 is that indicated to be worn. However, never add minus sphere until the total sphere becomes minus. The same strength of minus sphere must be added to each eye (otherwise an anisometropia will be induced) provided the retinoscopy and previous subjective findings have been accurate.

For example, from the examination under cycloplegia the following is found:

$$OD + 2.75S$$
$$OS + 2.25S$$

Four days later, after restoration of the power of accommodation, it is found that the above formula causes a marked blurring and an acuity of only 20/40, binocularly. Add a minus $0.12S$, then minus $0.25S$, and eventually a minus $0.50S$, until 20/20 is obtained. The following acceptable formula is derived:

$$OD + 2.75S \text{ combined with } -0.50S = +2.25S$$
$$OS + 2.25S \text{ combined with } -0.50S = +1.75S$$

The hyperope should wear as much plus sphere as he will accept.

(2) *Myopes.*—The myope, at the post-cycloplegic test, will usually accept his full correction. In no instance should he be given more minus than required to give his normal vision, consequently weak minus spheres are not to be added to the full minus correction at the post-cycloplegic test, although he will probably accept more minus readily.

The strength and axis of the cylinder should be checked on each eye separately. As a rule the full cylindrical correction will be accepted, even in hyperopes, and will require no reduction in strength although the sphere is reduced. However, it may be found that cylinders of high strength may not be accepted or tolerated unless the patient has worn such a correction previously. A very strong cylinder may have to be reduced in strength before being worn comfortably.

169. Correction of presbyopia.—In cases of presbyopes the correction for near vision must be obtained, either for reading glasses

or for bifocals. The usual distance considered for a reading correction is 33 centimeters. However, the patient's vocation and habits must be taken into consideration. If he has formed a habit, as working at a desk, his near correction will be for about 50 centimeters. The amount of plus sphere addition required will vary with several factors, principally age. The Jaeger, or some similar near vision card should be used at the distance the patient is accustomed to read, and plus spheres added to the distance correction in gradually increasing strengths, until Jaeger No. 1 can be read in comfort. It is better to add too little plus sphere for reading than too much. The total addition should never exceed plus 3.00*S*; if the patient is corrected for distance, he is, to all intents and purposes, emmetropic, and only 3 diopters of accommodation are required by the emmetrope for reading at 33 centimeters. Consequently, no more than 3 diopters are required even if the patient has no accommodative power as an addition for reading.

As a general rule in regard to the addition required for near vision the following plus spherical lenses will be required for reading in addition to the distance correction:

Age	Plus sphere addition
40	+0.50 *S* to +1.00 *S*.
45	+1.00 *S* to +1.50 *S*.
50	+2.00 *S* to +2.50 *S*.
55 and over	+2.50 *S* to +3.00 *S*.

Practically invariably the same addition in plus sphere will be required for each eye. Care should be taken in prescribing a different "add" for reading for each eye, such may indicate an error in the correction for distance, or in some instances, rarely encountered, may mean a difference in accommodative power of the two eyes due to disease or injury.

170. Transposition of formula.—Transposition of a formula may be useful in order to utilize a thinner lens, to compare two formulae, and to make similar prescriptions in the two eyes. In the transposition of any formula the sign of the cylinder is changed, and 90°

added to the axis to obtain the new cylinder. The new sphere is the algebraical sum of the sphere and cylinder. For example—

$$+3.00\ S \text{ with } -4.00\ Cx\ 90° = -1\ S + 4.00\ Cx\ 180°$$

and

$$-2.00\ S - 1.00\ Cx\ 90° = -3.00\ S + 1.00\ Cx\ 180°$$

and

$$+1.00\ S + 0.50\ Cx\ 180° = +1.50\ S - 0.50\ Cx\ 90°$$

and

$$+1.00\ S - 1.00\ Cx\ 90° = O\ S + 1.00\ Cx\ 180°$$

The transposition of a sphere does not change its optical value. The optical principles involved are those of rule (7) in the combination of lenses. For example—

$$+2.75\ Cx\ 45° - 3.25\ Cx\ 135° = +2.75\ S - 6.00\ Cx\ 135°$$

or (transposing)

$$-3.25\ S + 6.00\ Cx\ 45°$$

As an example, in the comparison of prescriptions we may determine by retinoscopy that a patient, in our opinion, should wear a minus 0.75 *S* plus 1.00 *Cx* 90°. He has been wearing habitually minus 1.00 *Cx* 180°. These two formulae appear at a glance to be quite dissimilar. Nevertheless, they are almost the same; transposing our findings we have plus 0.25 *S* minus 1.00 *Cx* 180°, and the difference between the two is only minus 0.25 *S*. Minus 0.25 *Cx* 45° and plus 0.25 *Cx* 135° appear at first to be two entirely different formulae, but actually there is a difference of 0.25 *S* between the two.

The optician who grinds the lenses may transpose a formula to obtain a lens that is thinner or thicker, as the case may be.

A formula may be transposed for the purpose of making prescriptions for the two eyes similar, that is, plus or minus cylinder for each eye, instead of a plus cylinder for one and a minus cylinder for the other.

171. Decentering of lenses.—Occasionally a spectacle lens may be decentered to obtain a prismatic effect. Decentering a plus sphere gives the effect of a prism base toward the direction of decentering (base will be toward the optical center). A decentered minus sphere gives the effect of base away from the optical center. The same is true of a cylinder decentered at right angles to the axis.

The prismatic effect of a decentered lens will vary with the refractive index of the glass, but as a rule, for every centimeter of decentering there will be produced as many prism diopters as there are diopters in the meridian which is decentered. For example, consider a plus 4.00 *S*; if the lens is decentered out (the optical center 1 cm. lateral

to the geometric center) the effect is a 4 diopter prism base out. Or another method—

$$\frac{10n}{d}=\text{number of millimeters decentering}$$

where n equals prism diopters required and d equals dioptric strength of the lens. For example, 2 prism diopters are required in a plus 4.00 S; $\frac{10\times 2}{2}=10$ millimeters. The optical center would have to be placed 10 millimeters to the nasal side of the geometric center in this instance.

Section XXI

OPHTHALMOSCOPIC EXAMINATION

172. Ophthalmoscope.—*a. Use.*—The invention of the ophthalmoscope by Helmholtz in 1851 opened a new field of possibility in the diagnosis of systemic disease as well as affections involving the eye alone. By the use of this instrument the interior of the living eye may be examined, that is, those structures behind the lens, the vitreous, retina, choroid, intraocular portion of the optic nerve, and the retinal blood vessels.

b. Description.—Essentially the simple ophthalmoscope consists of a mirror, plane or concave, with a perforation or "peephole" at the center. Rays of light are reflected by the mirror through the pupil illuminating the interior of the eye and the details of the fundus. The dioptric system of the eye itself is utilized in obtaining an image of the structures under observation through the aperture or perforation in the mirror. The instrument is augmented by the use of lenses, plus and minus spheres, so placed in a disc that any one desired may be rotated before the opening in the mirror.

c. Modifications.—There are many designs and modifications of the ophthalmoscope, of which the electric, which has its own source of illumination, is particularly useful, especially in the examination of patients who are bedridden, although the older type, as the Loring,

still has some distinct advantages which are not replaced entirely by the more modern electric types. The more popular models employed are those designed by May, Morton, Jackson, and Marple. Some of the electric ophthalmoscopes use prisms to deflect the emergent rays of light rather than mirrors. Further, some are designed to use ordinary 110-volt current through a transformer or from dry cells carried in the handle of the instrument. Regardless of the type or model, all ophthalmoscopes are designed for the purpose of inspecting the media and fundus of the eye.

d. Pupil in examination.—The ophthalmoscopic examination is accomplished more thoroughly through a widely dilated pupil and with the accommodation of the examinee relaxed. The reasons are quite obvious. In the examination of applicants for Air Corps training the ophthalmoscopic examination should follow refraction routinely, while the pupil is still widely dilated and accommodation paralyzed. The examiner should wear his own correction for error of refraction when using the ophthalmoscope.

e. Practice.—The student is advised that upon every opportunity he take advantage of the occasion to use the ophthalmoscope in a routine manner and that he adopt a definitely outlined procedure in order that no detail be overlooked, even where no pathology of the media or fundus may be suspected. Every fundus, normal or otherwise, is within itself a most interesting and instructive study, and every fundus is a new story, as no two are alike. The use of the ophthalmoscope is not limited to the ophthalmologist but is a diagnostic instrument that is utilized to an advantage by the internist, the surgeon, the pathologist, obstetrician, and the general practitioner. The latter should familiarize himself with its use as he does his stethoscope. But to be adept in the use of the ophthalmoscope, and particularly in the interpretation of ophthalmoscopic findings, will require an infinite amount of practice, perseverence, patience, and study; otherwise, the fundus of the eye may be a meaningless, although interesting and beautiful picture.

f. Abnormal conditions of fundus.—It is not possible nor practicable in this section to describe the various appearances of abnormal conditions of the fundus; the student is encouraged to avail himself of the opportunity to study the colored plates of Wilmer, Adam, and Clarke, and the stereoscopic plates of Oatman when possible, as so much more may be expressed by a picture, in colors, than by pages of description.

g. Light.—The ophthalmoscope should be used in a darkened room, or at least the amount of light falling upon the eye being

examined should be reduced to a minimum, that is, light from sources other than the ophthalmoscope.

173. Examination of media.—In the examination of the media the examiner, standing or sitting on the right side of the examinee when examining the right eye, holding the ophthalmoscope in his right hand before his right eye (in a manner similar to the retinoscope) approaches the examinee until the details of the iris pattern are seen through the aperture. The pupillary area will appear as a dull red reflex. Where there exists an opacity (in cornea, anterior chamber, lens, or vitreous) it will appear dark against the red background—a bit darker than it actually is, as it is seen partially by reflected light. The approximate location of the opacity may be determined by having the examinee shift his visual axis slightly from the right to the left, or up and down; if the opacity is anterior to the pupillary plane it will move "with" the eye movement, if it is posterior to the pupillary plane it will move "against" the movement of the eye. The strength of the lens before the aperture may be increased or decreased as desired, but with any change in the lens strength the position of the ophthalmoscope before the eye must be altered, that is, brought closer to the eye with a stronger and farther away with a weaker lens. The self-illuminating types of ophthalmoscopes are equipped usually with a rheostat which controls the amount of illumination, and faint and diffuse opacities may be seen more easily with illumination reduced (Wilmer). The examiner should always use his right eye in examining the right eye, and left when examining the left eye of the examinee.

174. Indirect method.—After the media has been inspected the fundus may be examined by the indirect method. And for this purpose the older type of reflecting ophthalmoscope, as the Loring, may be used to an advantage. The indirect method of ophthalmoscopy is not employed as frequently as it should be in many instances. It should be remembered that it has several distinct advantages; a greater portion of the fundus is seen at one time than by the direct method, and it is particularly applicable in high degrees of ametropia and where there exist slight opacities in the media. A plus 4 to 8 diopter lens is rotated before the aperture of the ophthalmoscope, and a plus 18. diopter lens (from the trial lens case) is held before the examinee's eye with the other hand. The examinee is directed to look directly forward. The plus 18. lens, held between the thumb and forefinger of the examiner, is held before the eye being observed and steadied by the other fingers resting against the forehead. The examiner then approaches the examinee until a view of the fundus is obtained. By shifting the position of the plus 18.

lens the details may be brought more clearly into focus. Various portions of the fundus may be brought into view by having the examinee shift his visual axis. The indirect method gives a magnification of 3 to 5 diameters and the image of the fundus seen is always inverted. It is to be remembered that the room must be darkened, and after the student has once seen the fundus clearly he may change the lens from the trial lens case, increasing or decreasing its strength, and change the strength of the lens in the aperture of the ophthalmoscope until he finds the combination best adapted for his purpose.

175. Direct method.—In the direct method of using the ophthalmoscope the examiner holds the instrument as near the examinee's eye as possible, using "right eye for right eye and left for left." The strength of the lens to be used in the aperture will depend upon the dioptric power of the eye being examined and the ability of the examiner to relax his own accommodation (taking for granted he is wearing his correction for ametropia). If the examinee is emmetropic and the examiner can voluntarily relax his accommodation no lens will be required in the aperture. As a rule the beginner will have some difficulty in learning to relax his accommodation and at first will prefer to use a weak concave lens in the aperture. He should learn to use the ophthalmoscope with both eyes open and in examining the fundus should imagine that he is looking at a picture some distance away in order to relax his accommodation. In exploring the fundus the position of the ophthalmoscope may be shifted and the position of the examinee's visual axis changed to bring into view different portions. By the direct method of ophthalmoscopy a magnification of about 14 diameters is obtained and the image is upright.

In the examination of the fundus by the direct method a change in the dioptric strength of the lens in the aperture of the ophthalmoscope of 3 diopters represents an approximate difference in depth of 1 millimeter. For example, with no lens in the aperture the level of the outer portion of the disc is clearly seen but the bottom of the physiologic cup is blurred; if a minus 3 diopter sphere in the aperture gives a sharp definition of the bottom of the cup we may conclude that it is 1 millimeter below the level of the disc itself.

176. Color of normal fundus.—The color of the normal fundus varies with individuals and in general is in keeping with the amount of pigment of the skin and hair, and depends upon the amount of pigment in the epithelial layer of the retina and in the choroid. Consequently the fungus of the pure-blooded negro is chocolate colored due to the fact that the amount of pigment in the epithelical

layer of the retina is so dense that very little of the underlying choroid may be seen through it. In the brown mulatto it may be described as being of a chocolate red color. In the Indian and Chinese it begins to assume a more stippled appearance, and in the latter has a distinct yellowish tinge. With the Caucasians it varies from an orange red in the Mediterranean types to a light orange red in the pronounced blondes. With the latter the retinal pigment is so scanty that the underlying choroidal vessels are seen distinctly and even certain portions of the sclera may show either faintly or distinctly, due to scantiness of pigment of the choroid. In the albino pigment is lacking altogether in the retina and choroid; so portions of the sclera that are not obscured by retinal and choroidal vessels are seen distinctly, especially toward the periphery.

177. Optic disc.—The optic disc (papilla) or the intraocular portion of the optic nerve is perhaps the most noticeable feature of the fundus and by its diameter as a standard of comparison the location of other points of interest are noted. The disc is located somewhat to the nasal side of the posterior pole of the eye (about 15°). It is roughly circular in form and from it the retinal blood vessels radiate. The disc is made up of innumerable nerve fibers of the optic nerve spreading out from the main trunk over the entire surface of the retina, in a manner somewhat similar to a strand of rope being frayed at one end and evenly distributed over a concave surface after passing through a perforation in the surface. However, these fibers are transparent. Consequently, the disc presents normally a depression or physiologic cup more or less centrally located. At the bottom of this depression there may be found the reticular or mesh-like strands of the lamina cribosa, the net-like fibers of the inner third of the sclera bridging across the opening. At the lamina cribosa the nerve fibers normally lose their medullary sheaths for the sake of transparency. The depth and diameter of the physiologic cup vary a great deal in normal eyes, and it may be so noticeable that it resembles a glaucomatous excavation. This portion of the disc is the paler in color, that is, whiter than the peripheral portion which may be described as being a pearl pink, which is derived from the capillaries invading its substance. The disc is usually paler on its temporal side, inasmuch as there are fewer nerve fibers emerging from this side. Immediately surrounding the disc and more noticeable on the temporal side there may be seen a white ring concentric with the disc, which represents, where it does exist, a portion of the surrounding sclera which is visible because the retina and choroid do not quite meet the disc margin.

Frequently there may be found an accumulation of granules of pigment from the choroid, usually on the temporal side of the disc which may fill in partially the scleral ring. In myopia the scleral ring may be so marked that it assumes a crescentic form.

178. Retinal blood vessels.—The retinal blood vessels emerge from the disc for their distribution over the retinal surface. The retinal circulation is terminal and normally does not anastomose within itself nor does it anastomose with the choroidal circulation. It can best be visualized after a review of its ontogenetic development. Occasionally there may be found an anastomosis (cilio-retinal) with a branch from one of the short posterior ciliary vessels, which enter the globe immediately around the optic nerve. Such an anastomosis is the exception rather than the rule.

179. Central area of retina.—*a. Blood supply.*—The central artery of the retina is the first branch of the ophthalmic (a branch of the internal carotid) after it enters the orbit. It enters into the substance of the optic nerve 7 millimeters to 12 millimeters back of the lamina cribrosa and passes forward to emerge on the optic disc where it divides into a superior and inferior branch, each of which subdivides into temporal and nasal branches. The bifurcation of the central artery may occur behind the lamina cribrosa, or on the other hand some distance after it has passed beyond the margin of the disc on the retinal surface. The two temporal branches (superior and inferior) appear to encircle almost completely the macular region and send numerous branches toward it. Veins accompany the arteries in their distribution and are distinguished from them by the fact that the arteries are of a brighter red appearance, are narrower, and in their course are more direct or less tortuous than the veins. The central vein emerges from the globe by way of the optic disc and optic nerve. "The vein has a longer course in the subarachnoid space of the optic nerve than the artery. Therefore, in cases of increased intracranial pressure, it is more subject to engorgement from compression" (Wilmer). The vein usually empties directly into the cavernous sinus, or it may join the superior ophthalmic vein.

The walls of the blood vessels or of the retina are transparent normally, and what is seen as a vessel is the column of blood within its lumen. The vessels, both arteries and veins, show a definite light streak along their axes. This is more pronounced, that is, wider and brighter, on the arteries. This difference is probably due to the reflex from the thicker media of the arterial walls, while the reflex on veins is due to the reflection from the anterior surface of the column of blood alone (Wilmer).

Where choroidal vessels are seen, as in the fundus of a blonde individual, they may be distinguished easily from the retinal vessels, as they appear flat, show no light streaks, anastomose freely, and appear deeply embedded.

b. Nutrition.—The retina as a whole is dependent upon two sources for its nutrition. The central artery of the retina with its branches takes care of the inner layers to the depth of the outer nuclear layer. The epithelial layer of the retina is dependent upon the capillary bed of the choroid underneath. Consequently it is readily understood that retinal degeneration will follow invariably degenerative or atrophic changes in the choroid.

c. Crossing vessels.—Veins and arteries frequently cross one another in the retina but never does a vein cross a vein nor an artery cross an artery.

d. Pulsation.—Venous pulsation in the retina is frequently encountered and usually is of no significance. It is diastolic and is more noticeable at the disk where the vessel bends abruptly. During the acme of systole the intraocular tension presumably rises to the extent that the walls of the veins collapse. Arterial pulsation, as seen with the ordinary ophthalmoscope, is considered as definitely pathologic and may be indicative of increased intraocular tension, orbital tumors, hyperthyroidism, and aortic insufficiency. Under good illumination and magnification arterial pulsation may frequently be seen in normal eyes.

e. Central area.—After locating the disc, if the area temporal to it is explored, the central area of the retina will be found. This region will be noted in contrast with other portions of the fundus, as it appears to be shunned or avoided by the larger blood vessels. It is an area about 7 millimeters in diameter and contains the macula lutea, the fovea centralis, the fundus foveae and the foveola. The macula lutea is an area centrally located in the central area of the retina about 1.5 millimeters to 2 millimeters in diameter, generally circular in outline. It is noticeably darker in color than other portions of the retina and frequently will be found to be somewhat granular in appearance. The fovea centralis occupies the central portion of the macula lutea and represents approximately the posterior pole of the eye, being about 3.5 millimeters to the temporal side of the disc. It is actually a funnel-shaped depression at the bottom of which is the fundus foveae, which is the thinnest portion of the retina. The minute foveola is at the center of the fundus foveae.

180. Periphery of retina.—*a.* The extreme periphery of the retina is quite difficult to bring into view. However, with a widely

CLASS	1	2	3
VISION	20/20	20/40	20/100
D.P.	30	35	
ESO.	M.T. 10	M.T. 10	M.T. 12
	M.T. 4 WITH P.D	L.T. 4	
EXO.	M.T. 5	M.T. 5	M.T. 7
HYPER	M.T. 1	M.T. 1	M T 2

P.D. M.T. 15 OR L.T. 3 – P.D. MUST EQUAL OR EXCEED ANY ESO.

R. LENS DIPLOPIA WITH IN 50 CM.

ANGLE 40° 40°

REFR. M.T. 1.5 △ TOTAL OR M.T. 50 CYL. TO READ 20/20

ACCM.

AGE	DIOPTERS
18	8.9
19	8.7
20	8.5
21	8.2
22	7.9
23	7.6
24	7.4
25	7.2
26	6.9
27	6.6

APEX IN ESO.

APEX OUT EXO.

APEX UP HYPER THAT EYE

FIGURE 49.—Summary of minimal visual requirements for flying.

dilated pupil and cooperative patient a view may be obtained slightly anterior to the equator. Each quadrant should be explored carefully.

b. Upon the completion of the ophthalmoscopic examination it is suggested that a miotic (eserine salicylate ½ percent solution) be instilled.

c. For a very complete review of pathological conditions of the fundus the student is advised to study carefully the colored plates from *Atlas Fundus Oculi*, by Dr. William H. Wilmer.

APPENDIX

ABBREVIATIONS AND REFERENCES

1. Abbreviations and signs used in ophthalmology.

A or Acc	Accommodation.
Am	Ametropia.
As	Astigmatism, astigmatic.
As. H	Hyperopic astigmatism.
As. M	Myopic astigmatism.
Ax	Axis (of cylindrical lens).
B	Base (of prism).
C or cyl	Cylindrical lens or cylinder.
cm	Centimeter.
D	Diopter.
E	Emmetropia, or emmetropic.
F	Field of vision.
H	Hyperopia, hyperopic, horizontal.
Hl	Hyperopia latent.
Hm	Hyperopia manifest.
Ht	Hyperopia total.
L or L. E	Left eye.
M	Myopia or myopic.
m	Meter.
M. A	Meter angle.
mm	Millimeter.
n	Nasal.
O. D. (R, or R. E.)	Oculus dexter (right eye).
O. S. (L, or L. E.)	Oculus sinister (left eye).
O. U	Oculus uterque (both eyes).
Oph	Opthalmoscope or opthalmoscopic.
P. D	Prism diopter.
P. L	Perception of light.
P. p	Punctum proximum (near point).
P. r	Punctum remotum (far point).
Pr	Presbyopia.
R. or R. E	Right eye.
S or Sph	Spherical lens.
t	Temporal.

T	Tension.
V	Vision, visual acuteness, vertical.
w	With.
+	Plus or convex.
−	Minus or concave.
=	Equal to.
⌓	Combined with.
∞	Infinity (20 feet or more distance).
′	Foot, minute.
″	Inch, second.
‴	Line.
°	Degree (prism).
∇	Centrad (prism).
Δ	Prism diopter.

271818°—40——18

2. References.—The part of this manual devoted to otolaryngology is not intended to be a textbook on otolaryngology, nor is it written for the purpose of supplanting existing textbooks on the subject. The purpose of the outline is to stress important points in the examination of the eye, ear, nose, throat, and adjacent structures, to enumerate and explain the disqualifying findings prescribed in regulations, to review certain conditions affecting these parts of particular importance to the flyer, and to bring out certain practical points in the treatment of these conditions.

No attempt has been made to give a detailed description of the anatomy or the physiology of the parts under discussion, except the labyrinth, as these are fully described in the standard anatomies and textbooks of otolaryngology.

The material presented in this manual was derived from lectures on the examination of the eye, ear, nose, and throat given at the School of Aviation Medicine during the past several years. It is obvious that such a manual must be, of necessity, a compilation from various texts and authors. Further, the student should have reviewed clinical ophthalmology or should study some standard text in conjunction with this manual.

The following smaller texts are recommended:

Diseases of the Eye, by Sir John Herbert Parsons.
Diseases of the Eye, by Charles H. May.
The Eye, by C. W. Rutherford.

For reference reading the following are recommended:

Textbook of Ophthalmology, volumes I and II, by Duke Elder.
Fuchs' Textbook of Ophthalmology.
Diseases of the Eye, by De Schweinitz.
Anatomy of the Human Orbit, by Whitnall.
Clinical Physiology of the Eye, by Adler.
Anatomy of the Eye and Orbit, by Wolff.
Anatomy and Histology of the Human Eyeball, by Salzmann.
Clinical Ophthalmology for the General Practitioner, by Ramsay.
The Pathology of the Eye, by Friedenwald.
Squint, by Claude Worth.
Atlas of External Diseases of the Eye, by Neame.
Medical Ophthalmology, by Moore.
Visual Field Studies, by Lloyd.
Methods of Refraction, by Thorington.
Practice of Refraction, by Duke Elder.

Outline of Ocular Refraction, by Maxwell.
Ophthalmic Optics, by Cowan.
Errors of Accommodation and Refraction, by Clarke.
Outline of Refraction, by Knighton.
An Illustrated Guide to the Slit Lamp, by Butler.
Slit Lamp Microscopy of the Living Eye, by Koby.
Diagnostics of the Fundus Oculi, by Oatman.
Atlas Fundus Oculi, by Wilmer.
Internal Disease of Eye and Atlas of Ophthalmoscopy, by Troncosos.
The Eye and Its Diseases, by Berens.

It is suggested that where some point is not made clear in the manual the student should avail himself of the opportunity of a better and more detailed explanation in the above texts.

AR 40–110 (Standards of Physical Examination for Flying) is not included in this manual for two reasons. Primarily, it would be a needless duplication as these regulations are available to the student in a bound volume, and secondarily the regulations themselves are subject to change from time to time. Upon the completion of each section of the manual the student should study carefully the paragraph of AR 40–110 pertaining to that particular phase of the examination, paying special attention to the procedure, precautions, and interpretation of findings.

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BY ORDER OF THE SECRETARY OF WAR:

G. C. MARSHALL,
Chief of Staff.

OFFICIAL:
E. S. ADAMS,
Major General,
The Adjutant General.

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